Utilization of Sorghum and Millets

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International Crops Research Institute for the Semi-Arid Tropics

Abstract

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This book is a compilation of 28 papers plus working group discussions concerning policy, practice, and potential relating to the uses of sorghum and millets throughout the world. The papers were presented at a workshop in Bulawayo, Zimbabwe, in Feb 1988.

Fifty-one participants from 14 countries representing several sectors and disciplines attended the workshop. The main purpose of this meeting was to explore opportunities for expanding crop utilization of sorghum and millets. As the crops have great diversity in usage, emphasis was placed on priorities among products, so that selection criteria could be established for breeding improved varieties and hybrids. Identification of regional crop use opportunities, both short-term and long-term, formed part of an overall effort to gain an integrated perspective.

The book has two sections. The first contains the 28 papers, which are grouped into four categories: Primary Processing of Food, Secondary Processing of Food, Industrial Uses, and Feeds. The second section reports the results of the working group discussions. A description of the methodology used to record the discussion results is followed by the spreadsheets used to obtain them and the overall recommendations of the workshop.

The book is a useful addition to existing literature and suggests directions for research and development efforts aimed at better utilization of sorghum and millets.

Résumé

Utilisation du sorgho et des millets. Cet ouvrage de synthèse rassemble 28 communications présentées lors d'un colloque tenu à Bulawayo, au Zimbabwe, en février 1988. Des procès verbaux de discussions en groupe sur les politiques, les pratiques et le potentiel relatifs à l'utilisation du sorgho et des millets dans le monde complètent l'ensemble.

Le colloque a réuni 51 participants originaires de 14 pays représentant plusieurs secteurs et disciplines. L'objectif poursuivi a été d'examiner des pistes nouvelles d'utilisation de ces cultures. Vu la grande diversité dans leurs usages, l'accent a été mis sur les produits de priorité afin de déterminer des critères pour sélectionner des variétés et des hybrides améliorés. L'identification des possibilités de valorisation régionale de ces cultures, tant dans l'immédiat qu'à long terme, a été prise en compte afin d'obtenir une vue d'ensemble.

L'ouvrage comprend deux parties principales. La première partie est constitué de 28 communications regroupés sur quatre thèmes : transformation alimentaire primaire, transformation alimentaire secondaire, utilisations industrielles, et aliments du bétail. La deuxième partie présente les résultats tirés des discussions en groupe. La méthodologie employée pour noter les conclusions des discussions est décrite et les tableaux utilisés pour les obtenir sont présentés. Enfin est dressée la liste des recommandations proposées par les participants du colloque.

L'ouvrage complète utilement la documentation relative à ce sujet et permet d'orienter des efforts de recherche et de documentation pour mieux exploiter le sorgho et les millets.

Resumo

Utilizaçao do sorgo e do painço. Este livro é uma compilaçao de 28 estudos e discussoes de um grupo de trabalho acerca de politica, prática e potencial dos usos do sorgo e do painço no mundo inteiro. Os estudos foram apresentados num seminário em Bulawayo, no Zimbabwe, em Fevereiro de 1988.

Ao seminário compareceram 51 participantes, procedentes de 14 países, representando vários sectores e disciplinas. A principal finalidade do encontro era explorar as oportunidades de expansao da utilizaçao do sorgo e do painço. Como é grande a diversidade dos usos das culturas, deu-se ênfase a determinar prioridades entre os produtos, de modo a se poderem estabelecer critérios para a produçao de variedades e hibridos melhorados. A identificaçao das oportunidades de uso de culturas regionais, tanto a longo quanto a curto prazo, fez parte de uma iniciativa global destinada a obter uma perspectiva integrada.

O livro está dividido em duas secçoes. A primeira reúne os 28 estudos, agrupados em quatro categorias: Processamento Primário de Alimentos, Processamento Secundário de Alimentos, Usos Industriais e Forragens. A segunda secçao apresenta os resultados das discussoes do grupo de trabalho. A descriçao da metodologia empregada para registar os resultados das discussoes seguem-se os gráficos utilizados para os obter e as recomendaçoes gerais do seminário.

O livro é um útil acréscimo à literatura existente e sugere direcçoes para pesquisa e iniciativas de desenvolvimento que visem uma melhor utilizaçao do sorgo e do painço.

Utilization of Sorghum and Millets

Edited by
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ICRISAT
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Industrial Uses

Feeds

Foreword

This book is the result of an international workshop at Bulawayo, Zimbabwe, 8-12 Feb 1988. The workshop was hosted by the SADCC/ICRISAT Sorghum and Millets Improvement Program based in Matopos, Zimbabwe. **Summary Proceedings of an International Workshop on Policy, Practice, and Potential Relating to Uses of Sorghum and Millets** were published by ICRISAT in 1988.

Reflecting the great diversity in usage of these two cereal crops, this book emphasizes priorities among products to establish selection criteria for breeding improved varieties and hybrids with specific end uses in mind. A consensus on the priorities among products will help give direction to crop improvement activities. Priorities for crop uses vary from location to location and these are reflected in the discussions. Another objective of this publication is to share experiences rather than to merely present findings from specific pieces of research.

The system of international agricultural research centers began with the founding of the International Rice Research Institute in the Philippines in 1962. Its focus has been very much on the production of food. In recent years, India and China have become self-sufficient, and are even exporting food grains. Zimbabwe consistently has surplus and exports. Nigeria, Malawi, Zambia at times have excesses.

In view of these developments, recognition of the importance of expanding opportunities for crop utilization is growing. ICRISAT, for example, seeks to develop a global strategy for food technology and crop utilization.

Sustainability of production is a much-heard phrase these days. The international centers are therefore looking for ways to diversify agriculture—crops, livestock, and agroforestry—and to improve market opportunities.

We recognize that there are short-term and long-term objectives. For example, there are useful tests for evaluating thick porridge made from grains of different sorghum varieties. Looking to the future, is it possible to sufficiently increase feedlot activity to reduce damaging livestock pressure on the range?

The market is so dynamic that prices and policies are apt to change before substantial contributions from research and development are evident. For this reason, the workshop participants were encouraged to express basic ideas and to ignore existing price/policy issues or constraints.

While we are specifically interested in sorghum and millets, we recognize that developments with other crops may be relevant. I understand, for example, that about 30% of the paper pulp produced in Denmark includes straw from small grains. The Carlsberg Laboratory is using rape and stem material to make construction board. Sorghum and millet straw may well be used for such products. Petrol in Zimbabwe and Malawi is blended with alcohol from sugarcane. Alcohol can be produced with equal efficiency from sweet-stemmed sorghum, and sorghum may have advantages as a companion crop with sugarcane.

There are two major sections in this book. The first part comprises 28 chapters presented in four groups: Primary Processing of Food, Secondary Processing of Food, Industrial Uses, and Feeds. The material presented in this section should help scientists broaden their perspectives of crop utilization. The authors represent both public research agencies and the business community. Their backgrounds and interests are widely divergent and reflect area-specific crop uses. The second section consists of recommendations that emerged at the workshop and includes the working group discussions in the form of spreadsheets. Lastly, keeping in view the importance of the workshop in the context of contributing significant findings to the scientific community, the list of participants in the workshop is given as an appendix with their present addresses. This will enable readers to reach the authors directly for any further interaction.

The working group discussions were a notable feature of the workshop. A novel methodology was adopted to obtain well-focused results. The participants were grouped according to expertise and given specific discussion formats. Participants were able to join more than one group discussion and were also encouraged to interact individually. A plenary session was then held where representatives from each group presented their conclusions to all participants.

It is hoped that this book will be a useful addition to existing literature and that it will provide directions for research and development efforts aimed at better utilization of sorghum and millets. Such utilization can play an important role in the economies of many countries in the semi-arid tropics.

L.R. House
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Preface

The utilization of traditional small grain crops like sorghum and millets is a topic of great interest to me. I remember one evening towards the end of 1982 when Ozzie Schmidt and I sat in a hotel room in Harare discussing plans to promote utilization of small grains through a SADCC regional project. We had different interests which converged nicely. He was interested in them as a vehicle for rural development. I was interested in them from a different angle altogether. I had been involved in breeding these crops and had naturally developed an extraordinary attachment to them.

Soon after our meeting, I found there were a number of other interested individuals. Among them was Professor Carl Eicher from Michigan State University, who at that time was a Visiting Professor of Economics at the University of Zimbabwe. Although I never anticipated such compatibility with an economist, somehow we agreed in many respects concerning small grain processing and utilization.

Many other individuals have contributed to the current concern with small grain productivity, processing, and utilization. A critical mass of small grain researchers, developers, and promoters has been thus established in Zimbabwe and in other SADCC countries.

Numerous conferences and workshops focusing on the food security crisis have been held in sub-Saharan Africa. Various proposals have addressed the critical imbalance between food production and the ever-growing population in the region. According to FAO, food production increased approximately 1.9% per year between 1961 and 1980. But countering this apparent progress is an increase in population of nearly 3% per year over the same period. This imbalance has resulted in a decline of 1.1% in per capita food production and has increased the demand for food imports. The sad truth is that the sub-Saharan food scenario continues to deteriorate.

Most analyses of the problem have focused on drought, the disarray of national economies, and the continent's tumultuous politics. Few have recognized that a new approach to development is required—a resource-based strategy.

A large percentage of the SADCC region lies within areas of marginal rainfall, where precipitation is usually less than 600 mm and unevenly distributed. The proportion of land that falls within the semi-arid tropics varies from country to country (for example, 5% in Zambia, 77% in Zimbabwe, and 100% in Botswana). To make matters worse, the region has recently suffered from drought. Of the seven cropping years from 1980 to 1987, five were drought years.

Sorghum and millets, because they are drought-resistant, are the cereal crops best suited to the semi-arid tropics. However, maize, a drought-susceptible crop, is grown more widely than the small grains. There are various reasons for this: maize is more resistant to bird damage, yields are high when rainfall is good, and maize is easy to process. Various government policies, too, have established a demand in the domestic cash economy for maize production.

Another reason given to explain the dominance of maize, that it is more palatable, has recently been proven incorrect. A National Market Test for small grain meal in Zimbabwe revealed that 45% of respondents preferred pearl millet meal and 31% preferred sorghum meal, while only 6% preferred maize meal. The remaining 18% had no preference. It is thus apparent that factors other than palatability led to the dominance of maize in areas of marginal rainfall. Probably most important is the drudgery involved in the processing of small grains.

Governments in the SADCC region have become increasingly concerned about the general trend away from the production and consumption of sorghum and millets in favor of maize. Alleviating the processing constraints of sorghum and millets should reverse that trend. Greater production of traditional grains will also result in better national and household food security because these crops are hardier and more nutritious than maize. These attributes can be enhanced if we prioritize our breeding programs.

Efforts in Botswana, Zimbabwe, and other SADCC countries to introduce dehuller technology are examples of regional focus on improving production of sorghum and millets. The objectives for introducing this technology are not merely to promote domestic production and consumption of these cereals, but to raise the value of agricultural production. Our dependency on imports will therefore diminish, while rural development will accelerate through increased employment, productivity, and income levels.

SADCC's Food, Agriculture, and Natural Resources Strategy, which was developed in 1986, is very much in line with the Lagos plan of action. The strategy consists of seven objectives.

1. Provide a framework to integrate SADCC's regional and national policies and projects, and to harmonize investments that cut across sectors such as agro-industry and human capital improvements.
2. Reinforce and facilitate the efficient growth of food and agricultural production in member states and to encourage intraregional trade.
3. Increase rural income and generate employment in member states in order to translate food needs into food purchases.
4. Assist member states in designing policies, programs, and projects to increase household food security and ensure an adequate diet for all.
5. Increase national and regional food security to ensure against poor harvests and natural disasters and to reduce dependence on external sources.
6. Foster the efficient development, utilization, and conservation of natural resources and the protection of the environment.
7. Generate domestic savings and foreign exchange to finance a gradual transformation of agriculture-dominated economies into economies that produce larger percentages of industrial goods and services.

One cause for poverty in Africa is the use of inappropriate technology. As the Nigerians say, we must laugh with the teeth we have even if they are few. The future development of this continent will depend much on the selection and use of raw materials and technologies suited to particular needs and resource endowments. I feel small grains have a major role to play in the development of our rural economies. We have thus far made only limited use of them. I believe new ideas on utilization will emerge from the topics covered in this book.

A critical mass of professionals is necessary to achieve sufficient momentum to mobilize resources for utilization of small grains for rural development. The next step is to establish a tradition of small grains research, processing, and utilization. To establish and sustain such a tradition, human resource development is vital to fulfill requirements in administration, research and development, standardization and control, education, and extension. The provision of trained personnel for these functions can be achieved through degree programs in food science, food technology, and nutrition at both undergraduate and postgraduate levels in specialized university departments. It is gratifying to note that this process is already taking place.

I believe that this book is a significant contribution to the improvement of the production of sorghum and millets both in the SADCC region and throughout the world.

S.C. Muchena
Deputy Secretary
Ministry of Lands, Agriculture and Rural Resettlement
Zimbabwe

Primary Food Processing

Evaluation of Cultivar Characteristics, Milling Properties, and Processing of Sorghum for Food Use as a Boiled Whole Grain

R.B.H. Wills[1] and M.R. Ali[2]

Abstract

The results of a study to determine the suitability of a wide range of high-yielding sorghum cultivars for food use as boiled whole grain are presented. Considerable variation in grain size within cultivars was found to be common, but this was undesirable because the milling of mixed-size batches had a marked detrimental effect on milling characteristics and yield. Cooking time varied with the extent of milling and was related to the type of endosperm, but it generally remained longer than for rice. Presoaking in water or treatment with alkali reduced cooking time to some extent. While existing hybrid cultivars are suitable for use as boiled grain if proper milling and cooking techniques are utilized, such usage would benefit by breeding programs that develop cultivars with the desired traits.

Introduction

Sorghum is used as food primarily in developing countries. The major products are bread or porridge prepared from flour. An alternative use in some countries such as India and Sudan is a boiled whole grain similar to rice. Consumption as a whole grain offers several advantages. It is simpler than rice to prepare, because only the outer bran layer (which hinders water absorption) and pigments (which are nutritionally undesirable) must be removed before boiling (Desikachar 1974, Price et al. 1980). Grain used for products prepared from flour also requires milling, but further processing involves considerable time and additional equipment to produce the flour. It is also safer to store the whole grain rather than flour to avoid degradation and contamination. In addition, potential exists for marketing sorghum internationally as a low cost substitute for rice.

Substantial plant breeding programs have resulted in availability of a large number of hybrid cultivars which are much higher yielding than traditional cultivars. However, their cultivation has been mainly confined to developed countries where sorghum is principally used as stock feed. Farmers in many developing countries tend to grow traditional varieties for family consumption and hybrids for sale in the market (Jambunathan 1980). While much of this resistance to eating hybrid cultivars stems from differences in appearance and physical properties, critical studies to identify problems in using the grain are lacking. Techniques to overcome these problems must be developed, and consumers must be educated in the use of these techniques. This paper presents data obtained from a study in Australia that addressed several problems associated with the use of hybrid cultivars as boiled whole grain.

Methodology

The study examined 250 sorghum samples, including 54 commercial and experimental hybrids, several inbred lines collected in Australia over six growing seasons, and 13 Indian hybrids. The samples were used for assessing a range of grain properties, although not all samples were used for each evaluation. Three types of characteristics were evaluated.

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Wills, R.B.H., and **Ali, M.R.** 1992. Evaluation of cultivar characteristics, milling properties, and processing of sorghum for food use as a boiled whole grain. Pages 3–7 *in* Utilization of sorghum and millets (Gomez, M.I., House, L.R., Rooney, L.W., and Dendy, D.A.V., eds.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Cultivar characteristics

These evaluations were largely visual. Characteristics investigated were:

- type of endosperm texture, presence of glumes, position of germ in relation to endosperm surface, grain color, and whether stylar or hilar;
- size grading of grain by mesh sieving; and
- measurement of grain weight; proportion of pericarp, germ, and endosperm; and color of ground grain.

Dehulling characteristics

A small abrasive dehuller (Pearl Test®, Klett Electric Laboratory, Japan) was used to dehull small samples (5 g) sorghum grain. The device operates by holding grain on an agitating disc which moves against a fixed corrugated metal disc. The dehuller measures grain hardness by determining the time required to remove exactly 10% of the original grain weight. Milling performance is determined by the size of grain kernels after dehulling. Milled samples are divided into six categories calculated as percentages of the whole grain. These categories are:

- unbroken kernels with germ attached;
- unbroken kernels without germ;
- broken kernels greater than 0.87 mm diameter;
- broken kernels less than 0.87 mm diameter;
- scoured pericarp; and
- scoured endosperm.

Cooking characteristics

Cooking performance of unbroken kernels was evaluated using the method described by Chakrabathy et al. (1972). The method involves placing small samples of grain (2 g) in test tubes in boiling water until the starch is gelatinized. Gelatinization is determined by the absence of white chalky spots when kernels are pressed between two glass slides. Determining factors are:

- cooking time;
- water absorption and swelling;
- loss of solids in the cooking water; and
- the effect of soaking unbroken kernels (in both water and solutions containing various chemicals) for various periods up to 24 h at room temperature on water absorption and cooking time.

Results and Discussion

Grain characteristics vary widely between hybrid Australian cultivars. Important differences affecting food usage are grain size, color, type of endosperm, and pericarp content.

1. Size distribution

The grain from most cultivars was characterized by large variation in grain size, from 4.80 to 2.80 mm in diameter. Where multiple samples of the same cultivar were obtained from different growing districts or in different seasons, the size distribution varied, although it did not appear to be affected consistently by location or year. Cultural and agronomic practicessuch as irrigation and fertilizerregime altered the mean size of grain, but did not eliminate size variation.

A frequency distribution of grain sizes in all samples was calculated and is presented as Table 1. In the commercial hybrids, no sample contained more than 80% of the grain in one size, and only three of 122 samples had 79% in one size. In the experimental hybrids, a greater proportion of samples exhibited narrow size distribution—three samples contained more than 90% grain in one size range, while 26 of 107 samples contained more than 70%. These latter samples, however, tended to have larger sized grain. It thus appears that hybrid cultivars have a tendency to produce grain of widely varying size. However, under more favorable growing conditions (such as would occur with experimental hybrids grown at research stations) small kernels would have tendency to increase in size while the large kernels would be unaffected. While grain size variation is of little importance when sorghum is used for stock feed, it is quite important for food usage. Grain in each size grade has different dehulling characteristics, with the large grain milling most rapidly. Milling of ungraded grain therefore results in either the small sizes being undermilled with adhering pericarp or the large grain being overmilled with excessive loss of marketable endosperm. It is thus necessary to initially grade the size of each batch of grain, and to mill each size separately.

Milling ungraded grain affects the yield of unbroken kernels. In this study, an average yield of unbroken kernels of 86% was obtained for size-graded grain. This contrasts with reports of losses up to 35% kernels during the milling of ungraded grain into flour with color acceptable to consumers (Reichert and Young 1976, Oomah et al. 1981). However, had

Table 1. Frequency distribution of grain sizes in 122 commercial and 107 research plantings of sorghum in Australia.

	No. of samples							
	Commercial hybrids[1]				Experimental hybrids			
Total grain (%)	4.00+	3.35+	2.80+	2.36+	4.00+	3.35+	2.80+	2.36+
91-100	0	0	0	0	3	0	0	0
81-90	0	0	0	0	7	2	0	0
71-80	0	1	2	0	8	2	4	0
61-70	3	1	18	0	2	7	0	0
51-60	7	16	9	0	4	12	15	0
41-50	4	34	22	1	3	23	11	0
31-40	7	35	15	2	4	25	18	0
21-30	17	14	31	4	9	11	15	0
11-20	20	10	16	14	18	16	9	11
00-10	64	11	9	101	49	9	35	96

1. Diameter sizes: 4.00+ is ≥4.00 mm. 3.35+ is 3.35-3.99 mm. 2.80+ is 2.80-3.34 mm. 3.36+ is 2.36-2.79 mm.

the grain been previously size-graded, the losses would undoubtedly have been much smaller.

Because international export standards for sorghum do not usually specify grain size, problems with different rates of milling are created. A mixture of cultivars is therefore recommended, since individual cultivars differ in their milling rates.

2. Color

While various cultivars had widely different pericarp color, this was unimportant after dehulling because no difference was discernable in the endosperm, which appeared white or creamy for all cultivars. However, it was often difficult to completely remove the pericarp without excessive milling due to grain shape, grain size variation, and position of the germ. In such cases, the presence of a highly colored pericarp was quite obvious and considerably downgraded its consumer acceptability. The presence of pericarp in all sorghum types affected cooking time similarly, however, and decreased nutritional value due to increased tannin.

An undesirable feature of sorghum for food is a heavy black hilum. This was present in all cultivars and was not removed during dehulling. It would be advantageous to produce cultivars with a colorless hilum, although this would upset agricultural practices where harvesting time is often determined by the blackening of the hilum.

3. Dehulling characteristics

The object of milling is to scour off the pericarp and (ideally) the peripheral endosperm, and it is important that this loss is accurately determined. The commonly used milling index is total loss of weight (often 10% milling loss), but this study showed that such an index can be misleading due to varying degrees of kernel breakage. Since small broken fragments are normally included in the milling loss, the extent of pericarp removal is frequently overestimated. The device used in this study for decortication was simple. It required only a small sample, but was able to quantitatively chart the course of dehulling with separation of the various sized fractions into small and large broken kernels and unbroken kernels. The method should be useful to sorghum breeders in the selection of dehulling characteristics.

The concept of milling to 10% loss is unrealistic due to the considerable difference in pericarp content between cultivars. The average mass of 100 pericarps is 7 g. It is also inefficient to mill a mixture of cultivars as considerable variation in hardness occurs between cultivars, so that different lengths of time are required to scour fixed proportions of kernels from different cultivars.

The yield of unbroken kernels decreased as the extent of milling increased. However, Figure 1 shows that yield decrease is rarely linear, with several break points occurring. The first break points occur in the peripheral endosperm, but at different depths in dif-

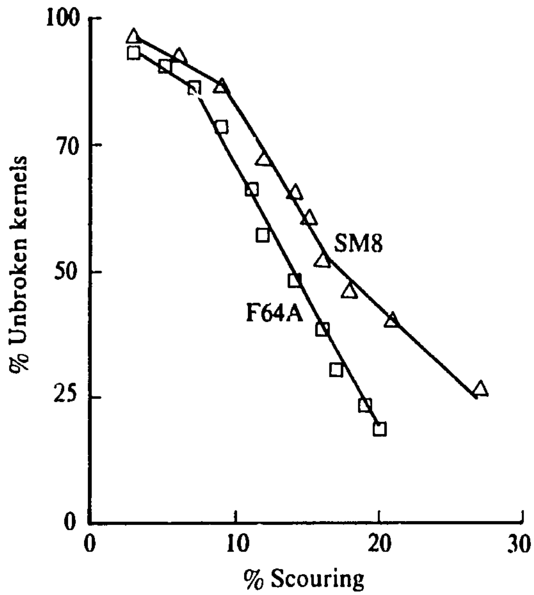

Figure 1. Effect of progressive milling on the yield of unbroken kernels in two sorghum cultivars.

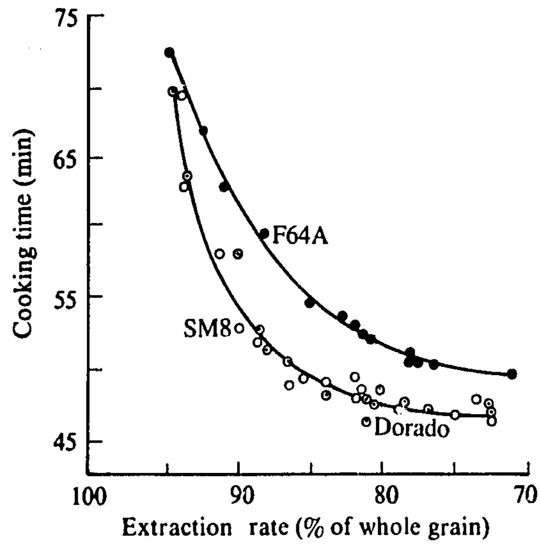

Figure 2. Effect of abrasive milling on cooking time of three cultivars of sorghum grain.

ferent cultivars. No reason is offered for this variation. The location of this break point is commercially important because of the reduced yield of unbroken kernel beyond this milling point. Decortication is not usually carried out commercially to the second break point due to the high level of kernel breakage.

Although most cultivars contained predominantly vitreous endosperm, unbroken kernel yield increased with increase of endosperm vitreousness.

4. Cooking characteristics

Cooking time varied widely between cultivars and ranged from 51 to 73 min for grain milled to 10% milling loss with 200% uptake of water and 5% loss of solids in the cooking water. Comparison with Indian cultivars used for food indicated a similar range of cooking times, as did comparison with several pure sorghum lines. It is generally accepted that sorghum endosperm has an inherent hard-to-cook characteristic due to the protein matrix which resists water penetration. Hybridization does not alter endosperm structure significantly. While cooking time is less for milled sorghum than for whole undehulled grain (about 90 min) (Rao et al. 1952), it is much longer than for other milled cereals. Rice, for example, takes 25-30 min. The time consideration is a deterrent to the use of sorghum as a rice substitute despite similar taste and appearance and the lower cost of sorghum.

Cooking time was greatly reduced as the extent of milling increased (Fig. 2). Considerable reduction occurred as the pericarp was being removed and continued until 3-4% of the endosperm had been removed. There was little further decrease in cooking time thereafter. A microscopic study of the cultivar Dorado showed that cooking time became constant when the peripheral endosperm, with its thick protein matrix, was fully exposed. The structure of the corneous endosperm can thus be considered the ultimate determinant of cooking time.

The use of increased milling of endosperm to reduce cooking time, however, leads to yield loss of unbroken kernel and increased loss of marketable endosperm. An alternative strategy to reduce cooking time is to disrupt the structure of the peripheral and corneous endosperm and thus allow faster penetration of water. Presoaking the kernels in water reduces cooking time and is a useful household method, but it is not of commercial value as the soaked grain must be dried again before cooking. Soaking grain in sodium hydroxide and trisodium phosphate may have commercial value because grain dried after soaking retained low cooking times (20-30 min). The action of these compounds probably alters the protein structure. Phosphate has greater potential since sodium hydroxide caused some yellowing of grain.

Recommendations

In spite of the generally negative attitude towards use of hybrid sorghum cultivars as food, such usage is possible provided improved milling techniques are utilized to allow uniform grain milling. Precooking treatment for domestic and commercial use acceptability reduces cooking time.

Breeding programs have increased yield efficiently, but should now give greater attention to improving quality of food grain. Criteria identified in this study as desirable in sorghum as a whole boiled grain are:

- uniform grain size of small diameter;
- thin white pericarp with no tests;
- Germ position level with or above endosperm surface;
- no black hilum or stylum;
- grain shape round or elongated (like rice);
- hard, corneous endosperm;
- uniform distribution of protein matrix in endosperm; and
- thin peripheral endosperm.

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Discussion

D.A.V. Dendy: Which dehuller design was used?

R.B. Wills: The Klett dehuller Pearl Test®.

R.E. Schaffert: What was the percentage moisture content of the samples?

R.B. Wills: 12%.

R. Jambunathan: How do you estimate the germ position level in relation to endosperm surface, and how are the results expressed?

R.B. Wills: The surface of the germ was visually assessed as being above, level with, or below the surface of the endosperm.

D.S. Murty: Observations at ICRISAT indicate that dehulled sorghum grains not only require less time to cook, but also yield higher volume.

R.B. Wills: We also obtained similar results.

V. Subramanian: What is the ideal shape for sorghum grains to produce dehulled grain, round or elongated?

R.B. Wills: The ideal shape is determined by the consumer. If the sorghum is being marketed as a rice substitute, it needs to have an elongated shape similar to rice. However, for other market situations, a round grain offers the advantage of maintaining a higher yield of unbroken kernel during dehulling.

An Analysis of Progress and Achievements in Regional Dehulling Projects[1]

O.G. Schmidt[2]

Abstract

The paper characterizes two interrelated problems facing the SADCC countries and the inhabitants of their dry areas and proposes two developmental objectives: (i) maximum utilization of the potential of the dry areas and (ii) attainment of household food security. Home dehulling of sorghum and pearl millet, important food crops for the dry areas, is one step in primary processing which has presented a problem. The relevance of mechanical dehullers to the food systems of these drought-resistant grains is discussed. The evolution of small-scale dehulling technology is described, and a program for its development and field testing, leading to wider dissemination in sub-Saharan Africa, is summarized. The experiences of that program are brought out by examining development in the postproduction systems of sorghum and millets. Priorities are identified for future regional work on sorghum and millets for human food.

Introduction

A substantial portion of SADCC's 70 million inhabitants live in dry areas where rainfall is less than 750 mm per year and occurs erratically or not at all in many years. These people, mostly subsistence farmers, face additional constraints: poor soils, land degradation, increasing population pressure on marginal lands, uncertain land tenure, long distances from sources of agricultural input and markets for their produce, infrequent visits from extension agents, limited options for food production, and low cash income for food purchases. A related set of problems can be defined at the national level:

- uncertainty of sufficient harvests;
- insecure or inadequate levels of foreign exchange earnings for food purchases to compensate for production shortfalls;
- unrealistic policies for the maximization of food sufficiency;
- unrealistic transportation infrastructures;
- poorly developed marketing;
- systems and policies favoring maize over indigenous drought-resistant cereals; and
- increasing dependency on cereal imports resulting in spiraling foreign exchange costs.

Two key developmental objectives for the dry areas emerge from these problems:

- to achieve food security for households of the poor (i.e., access to adequate amounts of food of adequate nutritive content); and
- to fully exploit the opportunities and limitations presented by the agroclimatic realities of the dry areas for food production.

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1. In the author's absence, the paper was presented by T. Rukini.

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Schmidt, O.G. 1992. An analysis of progress and achievements in regional dehulling projects. Pages 9–18 *in* Utilization of sorghum and millets (Gomez, M.I., House, L.R., Rooney, L.W., and Dendy, D.A.V., eds.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

The droughts in southern Africa from 1982 to 1985 forced national policymakers to examine the strategic importance of drought-resistant grains to both national and household food security. This change of focus led to renewed attention to the inhabitants of the dry areas. Until new and more advantageous systems of food production and more cost-effective techniques of land utilization are discovered for the dry areas, it is logical to emphasize indigenous foods, and the full utilization of food for human benefit at the lowest cost possible.

The presentations and discussions of this workshop must focus on these two goals if the knowledge is to become useful to the inhabitants of the dry areas.

Background

The vast majority of the producers and consumers of sorghum and pearl millet face the daily task of manually decorticating and pulverizing the grains before preparing the daily meal. Women and children labor hard and long dehulling these grains to remove the outer layers of fiber, which adversely affect the cooking quality and taste mouthfeel of the final product.

It was initially thought that the introduction of small dehullers into the rural areas would alleviate a home labor bottleneck and lead to increased consumption and utilization of sorghum and millet. This analysis, although not wrong, is incomplete.

The people of the Rift Valley of Africa (which runs through Tanzania and eastern Kenya), for instance, have no tradition of dehulling sorghum. The commonly grown varieties are brown, contain tannin, and have an endosperm so soft that it pulverizes on impact with a pestle. Dehulling has therefore been impossible. In order to reduce the bitter taste of tannin, dried cassava flour is added to the pulverized sorghum—an indigenous example of cooking with composite flour. Mechanical dehulling may be useful in removing the undesirable portions of these varieties.

We also know that urban dwellers do not have easy access to flour from dehulled sorghum or pearl millet, though it can be found in high-density peri-urban areas. But in southern Africa, packaged maize meal can be found everywhere. The potential of the urban demand for these flours from the drought-resistant grains is largely unexplored.

From experiences to date we can conclude that dehulling machines can make three positive contributions:

a. relieving woman and child labor;
b. making high-tannin cultivars more palatable and nutritious; and
c. generating a sustained urban demand for surplus production.

Dehulling Technology

The International Development Research Centre (IDRC) was created in 1970 by an Act of the Canadian Parliament with two major mandates: (i) to support research-for-development in Third World countries and (ii) to help strengthen indigenous research capacity in the Third World. The section dealing with postharvest activities within IDRC's Agriculture Division began supporting the work of African researchers on dehulling as early as 1972 in Nigeria. IDRC's strategy has been to support research intended to benefit rural dwellers. Since very little of Africa's sorghum and millet production is handled by national grain marketing systems, the primary point of intervention with the dehulling technology began at the rural level, near the source of production.

The hardware

The initial technical objective was to develop a simple mechanical device suitable for the needs of the producer/consumer of sorghum, pearl millet, and grain legumes. The dehuller consists of a metal shaft (rotor) around which a number of grinding stones or abrasive discs are evenly spaced (about 2 cm apart). This rotor is enclosed by a semicircular sheet metal barrel with a flat or rounded top. The barrel is partly filled with grain, and the abrasive material, spinning at 1500-2400 rpm, rubs against the individual kernels in the agitated grain mass. The result is a progressive abrasion of the outer layers of the kernels. The length of time the grain is retained affects the amount of material removed as abraded fines.

The first effective design resulted from the modification of an existing barley thresher. The work was done by the National Research Council of Canada's Prairie Research Laboratory (PRL), later renamed the Plant Biotechnology Institute. During the 1974-76 period, the PRL dehuller demonstrated its technical effectiveness on sorghums, millets, and cowpeas commonly grown in Maiduguri, Nigeria. It was also tried in Senegal in 1977 as part of a larger postharvest research project, but was found to be too large and unable to dehull the small batches of grain brought for dehulling by individual women. The same design, on the other hand, proved very successful in Botswana during the 1976-78 period, providing the basis for subsequent improvement.

From 1978 to 1980, Botswana's Rural Industries Innovation Centre (RIIC) scaled down the PRL dehuller and incorporated a trap door in the barrel, enabling the dehuller to deal with batches as small as 5 kg. It incorporates an aspirating system which removes the dehulled bran. It is suited to the daily dehulling requirements of 8000-10 000 people and has an economic break-even point of 1.5-2.0 t day^{-1}. In continuous flow operation it can process up to 5 t per 8-h shift. An exploded drawing of the RIIC dehuller is shown in Figure 1.

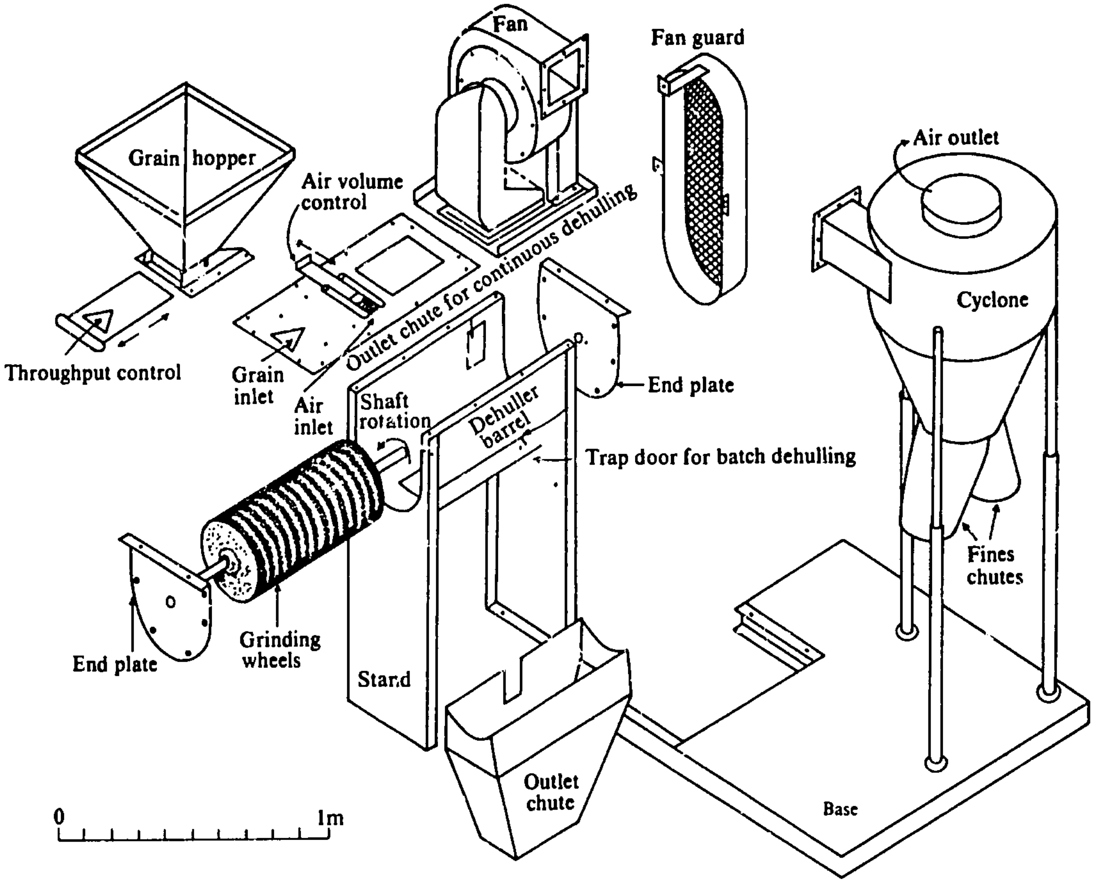

Figure 1. RIIC dehuller (Courtesy of Plant Biotechnology Institute, Saskatoon, Canada).

The RIIC dehuller, however, was frequently underutilized due to the sparse populations in many dry areas. Agencies in three countries therefore adopted a smaller dehuller, the MINI-PRL, which was originally designed for laboratory use. The MINI-PRL is available in several models, two of which do not have aspirating systems. Farmers using these devices must therefore hand winnow the grain to remove the abraded fines.

The Catholic Relief Services (CRS) in the Gambia, which have been working with the millet food system and how the dehuller fits into it, are marketing the MINI-CRS dehuller and are simultaneously developing the indigenous manufacturing capability so that technology can be delivered on a sustained basis (Nance and Colley 1985). Meanwhile, a Zimbabwean nongovernmental organization, Environment Development Activities (ENDA-Zimbabwe) has introduced the MINI-ENDA dehuller and has initiated a dehuller dissemination campaign financed by the Canadian International Development Agency (CIDA) (ENDA-Zimbabwe 1988). Much remains to be learned about the nature of the small grains food system in Zimbabwe, notably the question of the volume of effective demand for dehullers. Dissemination programs must seek to resolve such issues.

In Senegal, a joint activity between the parastatal equipment manufacturer SISMAR and the Institut sénégalais de recherches agricoles (ISRA) has developed the MINI-SISMAR/ISRA dehuller (Mbengue 1986). Prototypes are undergoing testing in 10 villages for effective response to the rural home dehulling problem. The design incorporates the winnowing of the abraded fines and has a smaller capacity than the RIIC dehuller.

The program of research for development

It is important to note that the hardware summarized above was developed with particular beneficiaries in mind. It was tested for comprehensive usefulness to its beneficiaries and is now undergoing wider dissemination in each of these countries. In addition, national scientists are using these designs in pilot projects in Ethiopia, Malawi, Mali, Niger, Tanzania, Uganda, Zambia, and other countries. The basic question addressed by these interventions is: "In what way is this technology useful?" In small rural communities, the technology tends to respond to a home labor bottleneck. At urban or peri-urban sites, the dehullers respond to a potential demand for flour previously unavailable from drought-resistant grain. As part of the process of providing the hardware, the researchers are clarifying the nature of the food system into which the dehullers might fit. The applied research into utilization complements the dehulling work.

A chronology of IDRC-supported research projects in the SADCC region can be found in Table 1. The current theme of these dehulling projects is best described as applied work on the processing and utilization of sorghum and millet, leading towards their increased consumption and production.

Table 1. IDRC-supported research on processing and utilization of sorghum and millets in SADCC countries.

1. Botswana

Botswana Agricultural Marketing Board, Private Bag 0053, Gaberone

- 1975-77 Sorghum Milling
  RIIC, Private Bag 11, Kanye
- 1978-80 Grain Milling
- 1982-84 Optimization of Dehuller Production
- 1985-87 Improved Dehulling Systems

2. Lesotho

Division of Agricultural Research, Box 829, Maseru 100

- 1988-90 Marketing Sorghum Products (proposed)

3. Malawi

Farm Machinery Unit, Chitedze Agricultural Research Station, Box 158, Lilongwe

- 1986-89 Grain Dehulling

4. Tanzania

Small Industries Development Organization (SIDO), Box 2476, Dar es Salaam

- 1979-82 Sorghum Milling I
- 1983-87 Sorghum Milling II

Sokoine University of Agriculture, Department of Food Science and Technology, Box 3006, Morogoro, Tanzania

- 1981-85 Sorghum Utilization I
- 1988-91 Sorghum Utilization II

5. Zambia

Small Industries Development Organization (SIDO), Box 35373, Lusaka

- 1987-89 Grain Dehulling

6. Zimbabwe

Silveria House, Box 545, Harare

- 1983-87 Sorghum Milling

Environment and Development Activities (ENDA), Box 3492, Harare

- 1985-86 Mini-Dehullers I
- 1987 Mini-Dehullers II

Program Experiences

The experiences of the national research-for-development projects on processing and utilization of sorghum and millets in sub-Saharan Africa are varied. Let us consider development in postproduction systems resulting from dehulling intervention.

Substantial change in Botswana

In the decade following 1975, rapid changes took place in dehulling technology. After it was demonstrated that the availability and convenience of sifted maize meal was causing a shift in cereal consumption away from sorghum, interest increased in improving techniques for drought-resistant grains. Using the PRL dehuller, the Botswana Agricultural Marketing Board (BAMB) showed that a demand existed for flour from dehulled sorghum in both urban and rural areas, assuming it could compete with low-priced maize flour. The PRL dehuller was subsequently redesigned by the RIIC, and 30 small-scale mills were established throughout the country. Interest in establishing these mills was stimulated both by the prolonged drought, in continuous presence since 1982, and by governmental policy supporting small-scale industrialization. Many of these mills were later converted into small grain factories which competed for consumer purchase of their processed flour by marketing their products in attractively labeled packages. Unfortunately, however, two-thirds of the mills are now severely underutilized. An organization composed of mill owners, the Botswana Mill Owners Association, was created in 1983 in part to lobby the Government on policies relating to sorghum. Several papers have analyzed and commented on the "Botswana experience" (Gibbs 1984, Schmidt 1987).

Achievements in dehuller dissemination

Since its inception in Botswana, the RIIC-designed dehuller has been sold to about 70 customers in neighboring countries, often through the mechanisms of aid agencies due to limited access to foreign exchange. Flour from dehulled sorghum is now available in large quantities and can be readily purchased by consumers. A small-scale processing industry has developed. The original intent to provide service milling has in large measure been superceded by complete small-scale factories (because of persistent drought families had very little grain for service milling). The existence of the mills, and evidence of a reliable supply of an acceptable alternative to maize, have changed the status of sorghum from that of a subsistence to a cash crop for many farmers.

Generation of useful hardware

Four variants of basic abrasive dehulling technology have been designed, tested, and modified for rugged village conditions. These variants are currently being introduced in many sub-Saharan countries.

Variance in food systems and needs

The conditions which facilitated the swift introduction of dehulling technology to Botswana did not exist in Tanzania, Zambia, Zimbabwe, or other countries. The problems of domestic dehulling and the competition between maize and small cereal grains differ from country to country. It is not enough to merely make new hardware available. We need to understand the rural dwellers' perception of their needs (if any) for dehullers, and responsive techniques of technology introduction must be developed carefully.

Additional benefits of dehullers

The small-scale sorghum or millet producer can benefit from the deployment of dehullers at two separate points of intervention in the food system. First, small machines in the rural areas contribute primarily to the enhancement of the quality of life for the producer/consumer, though an increase of consumption may occur (Fig. 2). Second, larger machines in peri-urban or urban areas can satisfy flour demand of consumers who are not producers, and can thus induce a sustained urban demand for increased production of drought-resistant grains. Adequate supplies of raw materials in the urban areas depend equally on producer prices and the maintenance of grading standards in the grain marketing system.

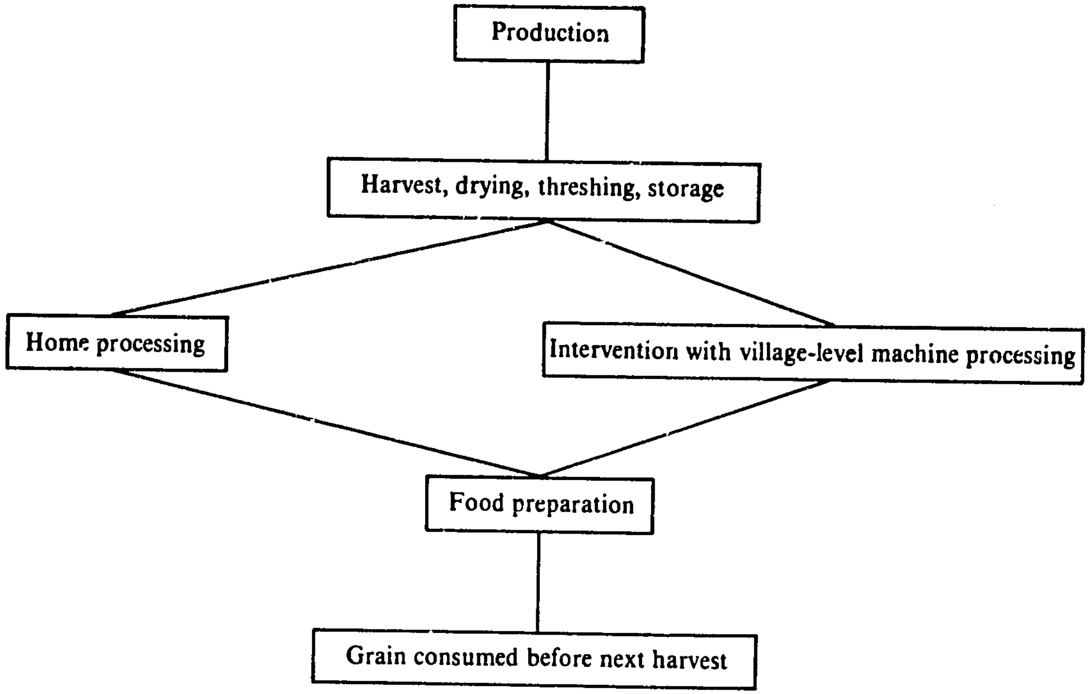

Figure 2. Effect on food system by introduction of rurally located dehulling machinery.

The deployment of national research resources for sorghum and millets

The dehulling-related projects supported in the region listed in Table 1 indicate that substantial numbers of researchers have been attracted to sorghum and millet postharvest work. A tendency persists, however, for some of the applied researchers to be technology- rather than problem-oriented. Much of the work undertaken has been limited and the results have not had significant impact on the ultimate beneficiaries. The applied researchers' abilities to document their experiences effectively must be strengthened to direct the acquired knowledge toward specific targets: policymakers, indigenous development agencies, specialist scientists, commodity improvement programs, and industry. Systems thinking is admittedly not easy, and has to be encouraged and practiced more widely.

Intercountry collaboration

Botswana's RIIC has become a reference point for dehulling technology. This intercountry cooperation is a welcome and useful development. Also making an impact of regional significance was the 2-6 Jun 1986 workshop ambitiously designated "New and Improved Foods from Sorghum: a Food Strategy for the Semi-Arid Zones". The workshop was organized by Sokoine University of Agriculture with funding from the British Overseas Development Administration (ODA). Although few new foods were introduced, the workshop served as an important forum for exchanging experiences on the processing and utilization of sorghum and millets. The SADCC Food Security Project which deals with postharvesting, the Post Production Food Industry Advisory Unit, coordinated the workshop.

New problems

New kinds of problems and opportunities have resulted from dehuller intervention. Upstream, the producer seeks to adjust production systems and sowing patterns. Downstream, the consumer seeks to characterize food product quality and relate it to varietal grain quality characteristics.

Research for development

There are four stages involved in understanding the process of research for development:

1. identification or recognition of a widespread problem or opportunity;
2. generation of a technology (by invention, adaptation, or adoption) likely to solve that problem;
3. verification, in concert with the intended beneficiary, that the technology is technically sound, economically viable, and socially acceptable; and
4. wide-scale dissemination to bring the solution and the technology into full utilization.

These stages are not mutually exclusive, and a good deal of interaction exists between them. For instance, the experiences gained in field testing may require refinement of the problem statement, and design changes may be necessary before field testing can again be undertaken. However, I feel that designating these stages is useful for tracking the effectiveness of strategies for executing applied research.

The most recent projects listed in Table 1 are located at stages 3 and 4, indicating substantial progress by applied researchers in the region.

Involving the international community

Two recent events were important milestones in the coming of age of sorghum and millets.

First, sorghum and millets featured prominently at an international workshop on "Household-Level Food Technologies for Improved Young Child Feeding", held in Nairobi in 1987 and co-sponsored by IDRC, the Swedish International Development Agency (SIDA), and the United Nations International Children's Emergency Fund (UNICEF). In addition to breastfeeding, the workshop examined two techniques for preparing supplementary foods: the use of lactic acid fermentation to produce the thin soured porridge *uji*, and the use of flour from germinated cereals for dietary bulk reduction from indigenous food crops. The workshop was attended by pediatricians, nutritionists, food scientists, cereal chemists, and nutrition promoters. Also discussed were the nutritive, toxicological, and pathogenic contamination aspects of children's diets. Recommendations focused on further work, both basic and applied, in these technologies, many of which called for uses of indigenous raw materials. The proceedings should be of great interest to the participants of this workshop.

Second, an informal grouping of research and development donors, the Group for the Assistance with Systems Relating to Grains after Harvest (GASGA), at its annual meeting in Jun 1987, invited Dr Muchena, Dr Moshe, and me to present a half-day symposium focusing on the small grains food systems in the SADCC region. This was followed by a 3-day intensive workshop at Matopos in mid-October, attended by scientists from southern Africa and representatives of GASGA. The workshop's main objective was to jointly identify research and development areas in sorghum and millets which needed further work. The proceedings of both meetings will be published by GASGA (c/o Dr Peter Prevett, Storage Department, Overseas Development Natural Resources Institute, London Road, Slough, SL3 7HL Berkshire, UK), and, it is hoped, will provide useful information to both donors and recipients.

Issues

Based on the experiences of the dehulling projects, certain general issues can be identified. The issues relate to both technology transfer and to drought-resistant grains.

Adoption rate

The rate of adoption of innovative technology has been slower in many countries than in Botswana. This may be due in part to incorrect or incomplete characterization of the problems of the target group resulting in inappropriate dehuller intervention.

Reaching the target group

The target group can benefit from interventions aimed either directly or indirectly at them. The small-scale millers can deliver a dehulling service to the rural dweller. Alternatively, they can use rural raw material to provide a processed product to a rural or urban consumer.

Continuous characterization of the problem

Extreme care must be taken to identify the actual problem, and not merely its symptoms. In the process of technological intervention, it is likely that other events occur in the environment, necessitating reanalysis and redefinition of the problem.

Innovations must always be evaluated in a broad economic context. The introduction of dehullers may benefit not only the rural female, for example, but labor in general, since opportunities for income are generated at several points along the food chain. Consumers, millers, and hardware manufacturers are all potential beneficiaries of the new technology. Conventional calculations for returns to investment should take note of the drought-prone environment, since the profitability of technology is affected by the presence or absence of droughts. It should also be recognized that every intervention results in losers as well as winners, and that amelioration of the detrimental results from a generally beneficial intervention must be considered.

Need for complementary inputs

A new technology, even if demonstrably needed, does not necessarily spread on its own; a system for the sustained delivery of the technology must often be established and nurtured with credit, business advice, manufacturing, and maintenance capability.

Broader policy issues

Several key questions can be posed concerning policy in the intervention of technology.

- Is the grain viewed by the producer as food, as drink, or as cash? Can a change in policy alter this view?
- Do price and marketing policies make it advantageous for the producers to sell all their produce, and then to buy a cheaper, subsidized, cereal?
- Can policy be adjusted comprehensively to permit sorghum and millets to compete effectively with the well-established and often subsidized maize system?
- Does exchange rate policy favor the import of cereals over local production?
- Do road development and transport systems to rural areas or easy access to larger centers help or inhibit growth point development?
- Does a policy exist for the promotion and protection of the small-scale food processing industry?

Possibly, the key issue for consideration is whether technology should be developed as a permanent or a transitional intervention. While the technology might initially be deployed in rural areas, and have the specific desired impact, it may later be relocated in larger groupings at the district level and utilized in a different way. The Botswana precedent suggests that economies of scale apply to distribution and marketing, and not to processing. (Several lines can be run in parallel for just the cost of the additional equipment).

The technology is useful for other grains

As part of a sorghum utilization project, the Ethiopia Nutrition Institute installed a mini-dehuller in a district town. After 3 months of operation, housewives had brought 4 t of grain, including barley, lentils, chickpeas, oats, faba beans, wheat, and field peas for dehulling, but not a single kg of sorghum.

Conclusions and Recommendations

The regional dehulling projects reviewed in this paper are filling an important gap and will certainly contribute to the increased use of sorghum and millets. I have not addressed the very important priority of the SADCC/ICRISAT Sorghum and Millets Improvement Program: to work towards the differentiation of varieties for different potential end uses (secondary food processing, industrial use, and animal feed). This subject will be covered by other chapters in this book. Based on interaction with national researchers, I make three general recommendations.

1. Prioritize future processing and utilization work

- Define and disseminate simple measurements of grain kernel characteristics and measurements of the preferred quality parameters of food end products.
- Document and characterize the current traditional food uses of pearl millet, which have received far less attention than sorghum.
- Investigate the nutritional intake from the total meal prepared and consumed, not merely the nutritional availability of the cereal component of the meal.
- Solve and ameliorate the problem of reduced bioavailability of proteins from cooked sorghum gruel.
- Emphasize practical utilization work to find products from sorghum and millets which possess some

of the convenient aspects of wheat-based foods, and improve the cooking and preparation procedures of indigenous food products such as *sadza*, *ugali*, and *uji*.
- Develop and maintain stronger interaction between the specialized sciences and research for development.

2. Strengthen national systems

National task forces should be created for the promotion of sorghum and millets . They should have the authority to define the changes desired and to effect implementation. Such task forces would have jurisdiction over the national production and utilization systems, and would chair annual meetings for review and goal setting. (This book will provide national policymakers with a variety of practical and feasible policy options.)

3. Strengthening links between national and international systems

Strategies should be developed for widening and intensifying the discussion between the SADCC countries and the donor community in order to develop goal-oriented interaction and mutual collaboration between national and international systems.

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Discussion

S. Dinat: The conclusions drawn by O. Schmidt appear not to address the need for inter-SADCC cooperation concerning the dissemination of research findings and technology throughout the region.

T. Rukini: IDRC and other donors do cater for national research programs which relate to specific countries. Therefore inter-SADCC relationships do not specifically limit the two programs for the whole region.

S. Ndoro: The dehulling process has overcome the labor bottleneck, but it has failed to integrate the cultural practices in the processing to make the grain tastier. Has anything been done to incorporate this aspect?

T. Rukini: No, but researchers are fully aware and will include this in their future work and selection criteria.

R. Jambunathan: What has been the experience with repairing the carborundum stones in Botswana?

T. Rukini: Availability of stones in Botswana is not a problem. However, other countries in the region have problems. The life of carborundum stones is variable depending on manufacturers. Tests in Botswana have shown that their stone has a life of 500-600 t. Good alignment and the avoidance of infraction of machinery helps to reduce breakage of carborundum stones during dehulling. Grain free from sand and stones increases the life of stones.

F. Mmopi: You have indicated that some countries in eastern Africa prefer brown sorghum. Why do they prefer brown to white sorghum?

T. Rukini: Generally, white sorghums are accepted in terms of palatability. In the case of eastern Africa, brown sorghums are preferred for cultivation because they are bird-resistant.

O. Olatunji: Are there any particular reasons why only IDRC dehullers are used?

T. Rukini: The success of the RIIC dehuller in Botswana influenced researchers who feel that it might have a similar impact in the SADCC region. Other types of dehullers exist in the region, but IDRC's research program on sorghum and millets is entirely dependent on PRL/RIIC-derived models. Other types are welcome, but the important aspects to consider are the availability and susceptibility to rural area situations and local manufacturing capabilities.

Wet Milling Nixtamalization and Micronization of Sorghum

L.W. Rooney[1]

Abstract

Sorghum was commercially processed by wet milling into starch, oil, and feed byproducts from the 1940s to the 1970s at Corpus Christi, Texas. The wet milling properties of sorghum are similar to those of maize. Sorghum starch and oil are nearly identical to maize starch and oil. Sorghum is slightly more difficult to wet mill than maize–the recovery of starch is lower. The phenolic pigments of red sorghum affect color of the starch, and the sorghum gluten does not contain sufficient carotenoid pigments to command premium prices from the broiler industry. However, certain sorghum hybrids, i.e., those with yellow endosperm, white pericarp, and tan plant color have outstanding potential for wet milling. Waxy, yellow endosperm sorghum hybrids have good potential. The technology is available, but the relative cost of sorghum to maize is critical. Sorghum must be lower in price than maize before it can be used. Nixtamalization is the conversion of maize into tortillas by cooking and soaking maize in alkali ($Ca[OH]_2$) or the leachate of wood ashes. The cooked maize (nixtamal) is stone ground into masa, which is formed into flat pancakes that are baked into tortillas. This process originated in Mexico where maize tortillas are the major staple bread. Sorghum is used for tortillas in Central America and in southern Mexico. Sorghum for tortillas has thick white pericarp, tan plant color, and an intermediate texture. Maize and sorghum mixtures are often utilized. The nixtamalization process is a potential way of producing new products in other areas where corn and sorghum are consumed.

Introduction

Nearly 250 000 t of sorghum were wet milled each year for more than 20 years at Corpus Christi, Texas. Both waxy and nonwaxy sorghum starches were obtained. The composition of maize and sorghum grains and the starch properties were similar. Sorghum wet milling was discontinued in 1972 due to the expansion of feedlots in Texas and subsequent higher prices for sorghum compared with maize.

Watson (1984) has reviewed maize and sorghum wet milling. The whole grain is soaked in dilute sulfurous acid at 5-52°C for 30-40 h in a counter current steeping procedure. The steeped kernels are degerminated by attrition grinding in a water slurry. The germ containing the oil is separated by hydroclones. Oil can then be extracted from the germ fraction. The degerminated residue is finely ground in an attrition mill which releases starch granules from the protein matrix and cell walls. The fiber is separated by sieving; the starch is separated from the protein by a series of hydroclones. The starch is washed and can be dried, derivatized, or converted into a wide array of products including sweeteners, syrups, crystalline sugar, and adhesives.

Although the basic principles of wet milling of maize and sorghum are the same, the following small differences significantly affect the process:

1. Professor of Food Science and Agronomy, Cereal Quality Laboratory, Texas A & M University, College Station TX 77843-2474, USA.

Rooney, L.W. 1992. Wet milling nixtamalization and micronization of sorghum. Pages 19–21 *in* Utilization of sorghum and millets (Gomez, M.I., House, L.R., Rooney, L.W., and Dendy, D.A.V., eds.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

- lower starch recovery from sorghum than from maize;
- greater difficulty in separating starch from protein and germ in sorghum;
- lower oil yields from sorghum;
- sorghum gluten does not have the carotenoid pigments desired by the broiler industry;
- the starch is frequently stained by anthocyanin and must therefore be bleached; and
- the bleached starch has altered cooking properties and appearance.

In general, sorghum requires a longer steep time than maize to modify the peripheral endosperm. Because maize is significantly easier to wet mill than sorghum, sorghum must be priced significantly lower than maize for economical wet milling. Caransa and Bakker (1987) summarized their experiences in designing a 150 t d^{-1} wet mill for starch production in the Sudan.

Sorghum cultivars with significantly improved wet milling properties exist. Several yellow endosperm varieties with improved starch protein separation and high starch recovery with low protein content have been identified (Norris and Rooney 1970). Kernel characteristics desirable for wet milling are: floury, yellow endosperm; large kernels; white colorless pericarp; absence of pigmented testa; and tan plant color.

The potential for selecting wet milling properties exists. However, some desirable wet milling properties (i.e., soft, floury endosperm texture) are the opposite of acceptable dry milling properties.

Nixtamalization and Tortilla Production

The process of cooking maize in a solution of lime water to remove the pericarp is called nixtamalization (Rooney and Serna-Saldivar 1987, Rooney et al. 1986, Serna-Saldivar et al. 1987). The cooked washed corn (nixtamal) is ground between lava stones to produce a dough (masa) which is formed into small, thin discs (tortillas) which are baked on a hot griddle. Tortillas from maize are the staple bread in Mexico and Central America.

Sorghum is used alone or mixed with maize in parts of Central America and southern Mexico where maize supplies are limited. People prefer maize tortillas, but significant quantities of sorghums are used for tortillas in Central America where sorghums with thick white pericarp, intermediate endosperm texture without pigmented testa, and purple plant color are used currently. Dorado, Tortillero, and Sureño are improved cultivars with tan plant color released recently in Central America.

Sorghum tortillas are produced from whole grain, but laboratory and commercial trials have indicated that decorticated sorghums have excellent potential for nixtamalization. Whole sorghum is cooked in excess water containing 0.5-0.8% lime (based on grain weight). The grain is held near the boiling point for 10-20 min and steeped for several hours or overnight. During washing, the pericarp is removed. The washed nixtamal contains 50% moisture; water added during grinding increases the masa moisture to 54%. The masa is shaped by hand to form tortillas (35 g) which are baked at 260-280°C for 30-40 sec on one side, 30 sec on the other side, and for 20 sec more on the first side. Table tortillas puff during the last bake. They are usually consumed fresh, so tortillas are made daily.

Sorghum with red pericarp or pigmented testa produce off-color tortillas because the alkali reacts with the phenolic compounds. Sorghum requires less cooking time than maize and the pericarp must be removed completely to obtain light color tortillas. Sorghum has a bland flavor, so mixtures of corn and sorghum are preferred to sorghum alone.

Nixtamalized maize and sorghum can be used to produce various snacks and the masa is cooked in water to produce thick and thin porridges and beverages (Vivas et al. 1987). In Mexico, sorghum grain is significantly less expensive than maize, so great potential exists for use of white sorghums for human foods.

Micronizing

Micronizing is a dry heat process used for both animal feeds and human foods (Rusnak et al. 1980). The process consists of heating grain kernels until they nearly explode. The hot kernels are then crushed through a roller mill to produce a thin flake. In the United States and Europe, micronizing utilizes gas-fired infrared burners to generate the heat. Ordinary corrugated roller mills are used to crush the heated kernels.

Micronized grain can be ground to produce a wide array of partially cooked food products. Tempering the grain with water prior to micronizing and adjusting the roller mill can increase the amount of gelatinization to create products with various characteristics.

Micronizers are used to precook grits and barley for brewing. The process does not require steam and is more maintenance-free than processes using steam flaking, high temperatures, high pressures, extrusion, and even Brady-type low cost extrusion. Micronizers can be easily constructed in rural areas with good machine shops and access to roller mills. They are worthwhile trying since the Brady low cost extrusion process does not work for cereals because of high energy and maintenance requirements. The Brady works well with soybeans because of the lubricating effect of the oil. Combinations of soy and sorghum can be processed with a Brady, but these combinations could also be micronized.

Sorghum varieties differ significantly in their response to micronizing (Rusnak et al. 1980). Waxy sorghums expand and are more easily processed than nonwaxy sorghums. Kernels with higher proportions of endosperm are more easily processed than others which can be used to create different products. Wet milling, nixtamalization, and micronizing are processes used to process sorghum into foods on at least a limited basis. The increasing importance of sorghum in many countries for food use will provide opportunities to develop new foods that appeal to the increasingly sophisticated tastes of urban consumers. (This is especially important in countries such as Nigeria where governmental restrictions have been placed on wheat importation.) Modified micronization and nixtamalization procedures may be useful in transforming sorghum into more acceptable foods.

Acknowledgments

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Semiwet Milling of Red Sorghum: A Review

J.E. Cecil[1]

Abstract

Semiwet milling is a technique discovered and developed by the author at the Overseas Development Natural Resources Institute (ODNRI) for milling various tropical grains. In this method, moist sorghum, containing about 26% water equilibrated through the grain, is milled on standard wheat-milling equipment. Excellent results were obtained using a laboratory mill, which had been set up for milling wheat. No alterations or major adjustments were made to the mill. A good yield of fine flour, containing very little tannin, was produced from the grain of every variety of sorghum tested, including red, white, and broomcorn cultivars. In most instances, the flour was white. The flours were cooked in various ways. The products had a smooth but slightly chalky texture. In informal taste tests, virtually no taste of tannin was detected. Tests on the laboratory mill have shown that the method is widely applicable, but they have highlighted some limits and defined some limitations. Tests on a commercial mill are are planned. The ability to remove tannin from high-tannin varieties in a conventional roller mill may encourage wider cultivation of pest-resistant varieties, and it could permit utilization of currently unusable cultivars. The ability to produce high-quality flour could open new markets for sorghum in urban households, in foods currently based on other grains, and in entirely new foods.

Introduction

Most white flour is milled from wheat on conventional roller mills. Numerous researchers have tried to mill sorghum on roller mills, but separation of the constituents of the grain was always poor. The resulting flour was unattractive to consumers, and nothing developed from these attempts. This is unfortunate since many roller mills have been installed in developing countries, many of which are underutilized. Other techniques for milling sorghum produce a flour which is gritty and speckled and which often has an astringent taste. While these features are preferred in some communities and for some uses, they are likely to limit the wider utilization of sorghum in urban areas. Less obvious, but perhaps much more important, these coarse flours contain relatively high levels of fiber, and when they are made from red sorghums, of tannin. It is the tannin that gives the astringent taste. Both fiber and tannin are nutritionally undesirable. Fiber increases fecal loss of nutrients and minerals and tannin reduces protein digestibility.

At ODNRI, it was found that by proper pretreatment of the grain, sorghum can be efficiently milled on standard wheat roller mills giving a good yield of high quality fine flour. The unbleached flour, even that produced from red sorghum varieties, is usually almost as white as unbleached 70% extraction wheat flour. It has been used successfully in various culinary preparations–in sauces, gravies, biscuits, cakes, and, when mixed with wheat flour, bread. The pretreatment involves dampening the grain with considerably

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more water than used in dry milling, but with far less than used in conventional wet milling. The technique is called "semiwet milling".

Milling Procedures

The techniques of semiwet milling, using a laboratory roller mill (a Bühler MLU 202) for milling pearl millet, proso millet, and various sorghum cultivars, was fully described by Cecil (1986). The technique for milling sorghum involves the following procedures:

1. addition of about 20% water;
2. conditioning at 60°C for 6 h;
3. roller milling; and
4. passage of the middle offal fraction through a centrifugal sifter.

In conventional dry milling, relative humidity (RH) affects milling characteristics, but not to quite the same extent as it affects the characteristics of semiwet milling. During roller milling to produce fine flour, considerable energy is liberated as heat, particularly on the reduction rolls. In extreme cases, these rolls must be cooled. In semiwet milling, this heat is used to evaporate the moisture in the flour, but an adequate flow of sufficiently dry air must be maintained to remove the water vapor produced. When RH is low (below 40%) the moisture content of the flour produced by semiwet milling is less than 12%, sufficiently dry for long-term storage. Above this RH, the flour may need to be dried. At high RHs (over 80%), problems are likely to occur because moisture in the flour significantly changes its flow characteristics resulting in, for example, steep angles of repose. Until techniques are developed for overcoming these problems, semiwet milling cannot be recommended for highly humid conditions.

Cecil (1986) also described the efficiency of semiwet milling in separating the constituents of sorghum grain. Most of the work was done on Serena, a variety of red sorghum grown widely in Africa. Serena is unusual because it has a pink pigmentation in the endosperm which causes the flour to be pink. Other red sorghums of Africa, Asia, and Europe yielded nearly white flours when milled. Milling conditions were optimal when the moisture content of the grain fed to the mill was 26% and when the moisture had equilibrated throughout the grain. At this moisture level, the production of bran was maximized, and the extraction of fat, fiber, and tannin into the bran were at the highest levels. The milling tests were carried out with a standard wheat mill set up for milling wheat without alterations. It was subsequently verified that the results could be improved by varying different parameters.

The bran consisted of two fairly distinct fractions. About 8% passed through a 500μ screen. The fat level in the fine fraction was 50% higher, and its viscosity was much lower than that of the coarse bran. The fat extracts from the offal and from the flour were even less viscous. The viscosity is believed to be due to waxes, presumably from the surface of the grain. The level of long chain alkanes (saturated hydrocarbons) with 29 to 33 carbon atoms was about 16 times higher in the bran extract than in the offal extract.

The bran contained most of the tannin. The bran coming off the mill is damp, typically about 30% moisture, which is convenient for soaking it in an alkaline or acid solution to wash out the tannin, or for pelletizing it immediately in a composite feed. Clearly it is inconvenient if the bran must be stored, but because of its flaky texture, it will probably be easy to dry on a commercial scale.

The middlings (offal, sifter tailings) could be milled further to yield an additional small amount of flour. The chemical characteristics of this fraction are similar to protein-fortified whole grain. It is certainly valuable as human food.

Flour from Serena sorghum was of excellent quality except for its pink color. It had a soft, dense texture and was successfully used in bread in a mixture of 10% sorghum flour and 90% wheat flour. Biscuits made from 100% Serena flour had a pleasant chocolate color. Flours from several other red sorghums–from France, Ethiopia, and Kenya–have been produced. None of the flours tasted astringent when made into baked products. They were all white, but they retained a slightly chalky mouth-feel.

Broomcorn sorghum is a type of red sorghum grown primarily for the fiber in the panicles. In most broomcorn sorghums, the glumes are firmly attached to the grain and cannot be threshed off. Most broomcorn sorghums contain very high levels of tannin and fiber, but because of the extra layers of the glumes they cannot be successfully milled on abrasive mills. The tannin content makes them of very little nutritional value even to ruminants. It also renders them virtually inedible, and consequently the grain is usually thrown away. Grain of a broomcorn variety widely grown in Bolivia was successfully milled using the semiwet milling method. Because of the additional weight of the glumes, the yield of bran was unusually high. Nevertheless, a light buff-colored flour with no bitter taste was promoted in a 44% yield. It was used for various culinary purposes, including thickening soup and for making cakes. The products tasted good and no unpleasant after-effects were experienced, even after consuming considerable amounts.

To date, at least three sorghums with 2.5% or more tannin content have been semiwet milled to produce white or nearly white flour. So far there is nothing to indicate that sorghums with very high tannin levels (up to 10%) cannot be semiwet milled to produce acceptable flour. Tannin content was measured in the flours using Prices's modification of the vanillin/HCl test (Price et al. 1978). The lowest limit of detection was 0.02%.

The flour yields from all five sorghums tested were poor. In recent trials, however, after reducing the gaps between the second and third rollers, yields in excess of 70% were obtained with semiwet milling of French red sorghum, and Dobbs sorghum yielded 61% flour. Both had sharply lower levels of bran. It is probable that even better separation could be achieved using the Bühler MLU 202 by adjusting certain parameters. Regardless, the technique has already shown promise for commercial milling.

Conclusions

Although semiwet milling holds great promise, it has so far only been developed at a laboratory scale. Various problems will doubtless be encountered in scaling up the process. These will probably include:

- microbiological growth in the humid environment inside the mill;
- removal of residual moisture to produce dry products;
- screen and transfer system blockage due to poor flow characteristics of high moisture flour and other products; and
- the need to produce new equipment.

On the other hand, the potential advantages are enormous. They include the following.

- Efficient elimination of tannin from the primary product, thus helping sorghum breeders to balance pest resistance (both in the field and in storage) against organoleptic acceptability, allowing them to concentrate more on other characteristics of equal or greater importance.
- Removal of extraneous matter (dust, sand, stones, metal) by hydraulic separation is possible. It is much cheaper and equally as efficient as dry methods.
- It is widely considered that in many respects red sorghums are easier to grow than white sorghums. Red sorghums are potentially less costly than white sorghums, and semiwet milled flour from red sorghum is virtually as good as semiwet milled flour from white sorghum.
- Standard wheat milling equipment, already available throughout the world, can be used.
- Urban dwellers tend to think that sorghum is fit only for poor country folk. The availability of high quality sorghum flour could alter their prejudice against a crop which suffers from poor presentation.
- The availability of consistently high quality sorghum flour could lead to the use of the flour in new food applications.
- Varieties of sorghum currently discarded (e.g., broomcorn sorghums and other high-tannin varieties) can now be utilized for human consumption.

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Discussion

O. Olatunji: There is need to quantify the comparative advantages of the new process with existing known methods. It seems there are considerable disadvantages.

J.E. Cecil: The advantages are many (they are listed in my paper), but at the end of the day it is for the marketplace to decide. We still have a lot to learn about semiwet milling.

A. Carney: The advantage to industry of semiwet milled products is that there appears to be a better recovery of better quality material than by decortification and hammer milling.

A.B. Obilana: Can both Dr Cecil and Dr Rooney compare their semiwet and wet milling processes to the indigenous wet milling by some consumers in western and eastern Africa to make *ogi* or *uji*?

J.E. Cecil and L.W. Rooney: The products from semiwet milling and wet milling are totally different. The main product from wet milling is starch and that from semiwet milling is flour. In indigenous wet milling the moisture level of the grain is about the same as in semiwet milling but the method of grinding is totally different.

M.I. Gomez: Black tip is a consumer disadvantage in dry-milled products. Has the absence or reduction of black tip specks been estimated as a quality advantage?

J.E. Cecil: Not really, but it is all part of the apparent high quality of semiwet milled flour.

S.Z. Mukuru: You mentioned that French red sorghum produced white flour using the semiwet milling technique. May I know whether French red sorghum grain has the testa layer?

J.E. Cecil: The testa layer is part of the pericarp.

S.Z. Mukuru: In some cases white-looking flour produced from brown grains turns brown when wetted and cooked. Have you wetted and cooked the white flour you have produced from brown sorghum? What color did you get?

J.E. Cecil: All grain flours look darker when wetted or made into moist products, but semiwet milled flours have less color than most, both when dry or in cooked products. There is a sample of bread at the back of the room made from semiwet milled sorghum.

Organoleptic Implications of Milled Pearl Millet

R.C. Hoseney, J.M. Faubion, and V.P. Reddy[1]

Abstract

The characteristic mousy, acidic odor generated in ground pearl millet during brief storage was investigated and found to be unassociated with oxidative rancidity of kernel lipids. Odor generation required high moisture levels in grits, suggesting that the process is enzymatic. Fractionation and reconstitution experiments showed the odor precursor to be extractable with methanol (but not petroleum ether) and retainable on reverse-phase preparatory columns. When the methanol extract was further separated into water-soluble and water-insoluble fractions, the water-soluble fraction retained the ability to support odor generation. Ultraviolet scans of this active water-soluble fraction showed absorption maxima similar to apigenin, the aglycone of the major C-glycosyflavone present in pearl millet. The characteristic odor associated with storage was found when apigenin was added to methanol-extracted millet grits.

Introduction

Pearl millet (*Pennisetum glaucum* [L.] R. Br.) is grown extensively in the dry areas of western and southern India and along the periphery of the Sahara, where it is used as food for an estimated 400 million people. In these areas, traditional methods of decortication are still practiced (Fig. 1) (Varriano-Marston and Hoseney 1983). Pearl millet can be stored for long periods without deterioration if the kernels remain intact. Once the grain is decorticated and ground, however, the quality of the resulting meal deteriorates rapidly (Varriano-Marston and Hoseney 1983), often developing a unique acidic odor within a few hours. Recent investigations of this objectionable odor indicated that it did not result from classical oxidative changes in lipids (Kaced et al. 1984). The studies reported here were carried out to identify and characterize the compounds or processes responsible for the off-odor in ground, stored pearl millet.

Preliminary experiments analyzing the peroxide values of fresh and stored grits as well as the generation of hexanal in stored grits showed that oxidative changes in lipids did not generate the off-odors. Hexanal was found to be produced by oxidative rancidity, thus confirming the conclusions of Kaced et al. (1984). Gas chromatographic analysis of the fatty acids in fresh and stored millet grits were identical, suggesting that reactions involving lipids were not the source of off-odors.

Extraction of Odor Precursor

To further characterize the source of the odor, we extracted freshly ground millet grits with solvents of increasing polarity in an attempt to remove the odor precursor. By testing extracted grits as well as extracted grits reconstituted with their extracts (Fig. 2), it was possible to evaluate the ability of each solvent to remove the odor-generating compounds or precursors (Table 1). Petroleum ether extraction did not affect the

Table 1. Odor in millet grits after extraction and reconstitution.

Solvent grits	Extracted grits	Reconstituted
Petroleum ether	off-odor	off-odor
Chloroform	off-odor (less intense)	no odor
Methanol	no off-odor	off-odor
n-Butanol	Butanol odor	Butanol odor

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Hoseney, R.C., Faubion, J.M. and Reddy, V.P. 1992. Organoleptic implications of milled pearl millet. Pages 27-32 *in* Utilization of sorghum and millets (Gomez, M.I., House, L.R., Rooney, L.W., and Dendy, D.A.V., eds.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

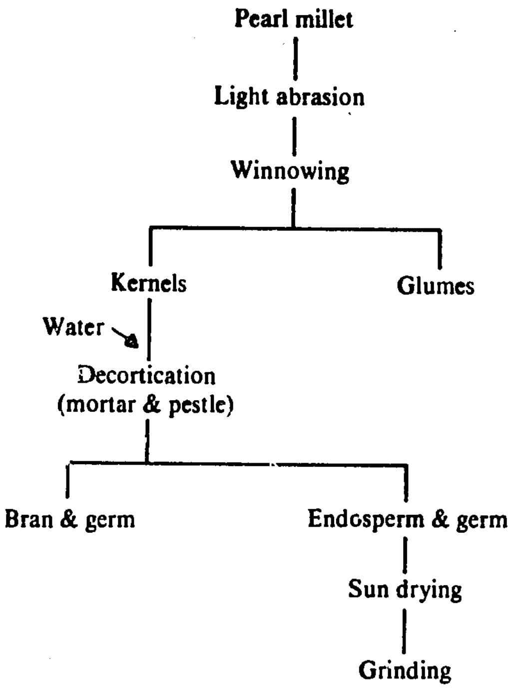

Figure 1. Traditional processing scheme for pearl millet.

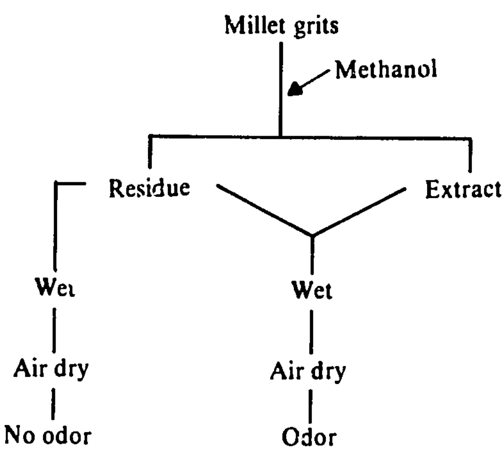

Figure 2. Extraction and reconstitution procedure for pearl millet grits.

ability of the resulting grits to generate the objectionable odor, thus reinforcing our conclusion that oxidative rancidity of lipids was not the cause of the odor. Chloroform extraction reduced the intensity of odor generated by treated grits. However, reconstitution did not restore odor production to its control levels. While it may have removed the odor precursor, n-butanol could not be evaluated because of the strong residual solvent odor that remained in the grits even after prolonged drying.

Methanol, however, was an effective solvent (Table 1). When tested, extracted grits failed to generate off-odors. In addition, methanol-extracted grits, when reconstituted with their extract, generated the characteristic odor at approximate control levels.

Freshly ground millet grits were subjected to methanol extraction after they had been wetted and dried to produce the off-odor (Fig. 3). The extracted grits had lost their odor and, when rewetted and dried, were no longer capable of generating the characteristic odor. However, reconstitution of extracted grits with their methanol extracts, followed by wetting and drying, resulted in odor production. These results indicate that methanol extraction is effective for removing not only the precursor of the odor, but the odor product itself. The odor compound is lost from the extract that supports odor generation when re-added to its parent grits, demonstrating that the precursor did not fully react when producing odor during the first cycle of wetting and drying.

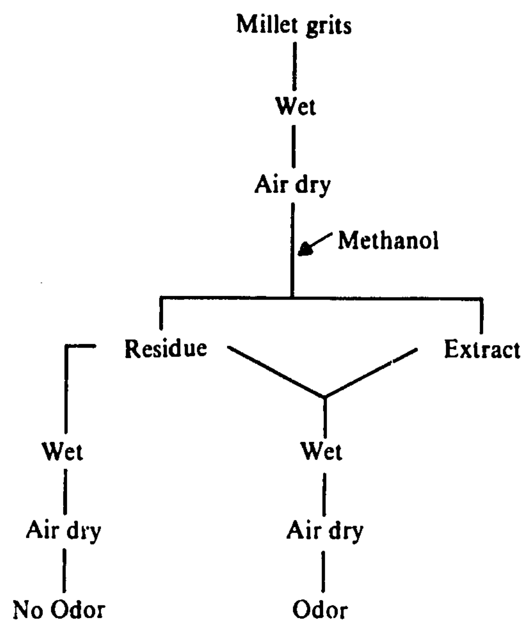

Figure 3. Procedure for the extraction, reconstitution, and testing of wetted grits.

Interchange Studies

The results reported by Lai and Varriano-Martson (1980) showed that objectionable odor was generated poorly or not at all in samples of low moisture content, suggesting that the odor generation process is enzymatic. To test whether the precursor and/or its putative enzyme were specific to pearl millet, the methanol extracts from millet and sorghum grits were interchanged (Fig. 4). Methanol-extracted sorghum grits, reconstituted with millet extract, were capable of generating the characteristic odor. The reverse combination, extracted millet grits plus extracts from sorghum, did not produce the odor when wetted and dried. Therefore, the precursor of the odor compound is specific to pearl millet. The enzyme generating the odor was not specific and exists in at least one other cereal grain (sorghum).

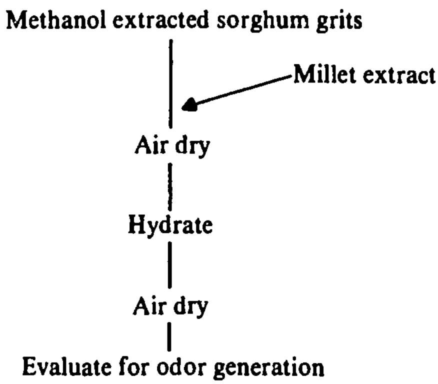

Figure 4. Procedure for interchanging extracted sorghum or millet grits with their methanol extracts.

Fractionation of the Methanol Extract

The active methanol extract (Fig. 5) was further fractionated into water and methanol solubles. Each subfraction was tested for its ability to support odor production. The methanol-soluble fraction had lost the precursor and was therefore unable to support odor production. Precursor presence in the water-soluble fraction was confirmed by its ability to generate odor when reconstituted with extracted grits.

Some naturally occurring plant phenolics (phenylpropenoids) are soluble in both water and methanol (Harborne et al. 1975). The phenolic acids present in fresh and stored milled grits were therefore determined by high performance liquid chromatography (HPLC).

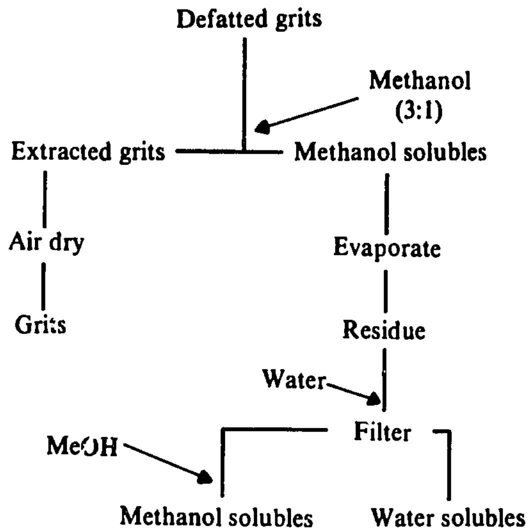

Figure 5. Extraction and fractionation of methanol extract.

Although at least five phenolic acids were identified in the methanol extracts of millet grits (Fig. 6), they did not change due to the generation of off-odor. Thus, chromatograms of the extracts from fresh and stored grits were undistinguishable on the basis of their phenolic acids. However, the chromatograms contained a large number of late-eluting, unidentified peaks (Fig. 5). These late-eluting peaks are often associated with flavonoid compounds with higher molecular weights (Hahn et al. 1983).

Chromatographic Fractionation of the Extract

Methanol extracts of millet grits were further fractionated by passage through small, reversed-phase preparatory columns ("Sep-paks"; Waters Associates). Flavonoids of higher molecular weight are more tightly bound by the column than are phenolic acids and therefore take either a greater volume of methanol or a stronger eluting solvent to eluate from the

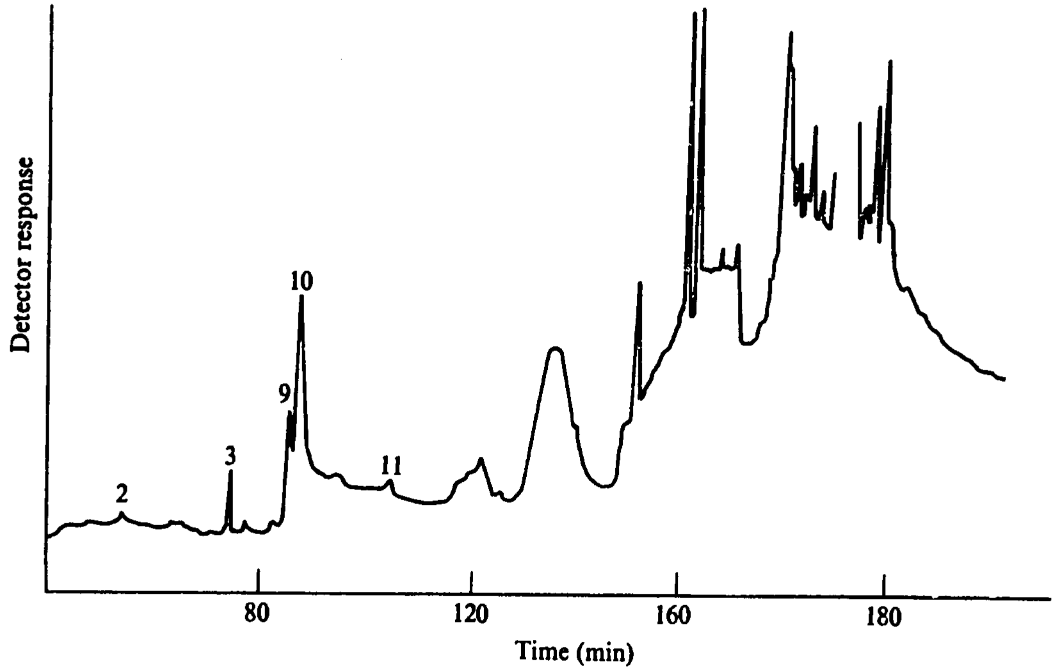

Figure 6. High performance liquid chromatographic (HPLC) analysis of phenloic acids from fresh millet grits and stored grits.

column. Using the procedure outlined in Figure 7, methanol extracts were fractionated into column eluant and column retentate. Recombination with extracted grits showed that only the column retentate produced the odor. The data thus indicated that the precursors of the mousy, acidic odor in pearl millet are potentially flavonoid compounds of high molecular weight.

Reichert (1979) reported the presence of at least four characteristic flavonoid glycosides in pearl millet. These compounds were unique in being C-glycosylflavones. Although usable quantities of the pure glycoside were not readily available, apigenin, the flavone aglycone of these compounds, was available. The ultraviolet spectra of apigenin and the active, water-soluble fraction of methanol extracts both showed similar absorption maxima.

Apigenin Supplementation

If enzymatic action on one or more of the native C-glycosylflavones was the cause of off-odor generation, enzymatic modification was more likely in the aglycone rather than in the carbohydrate component

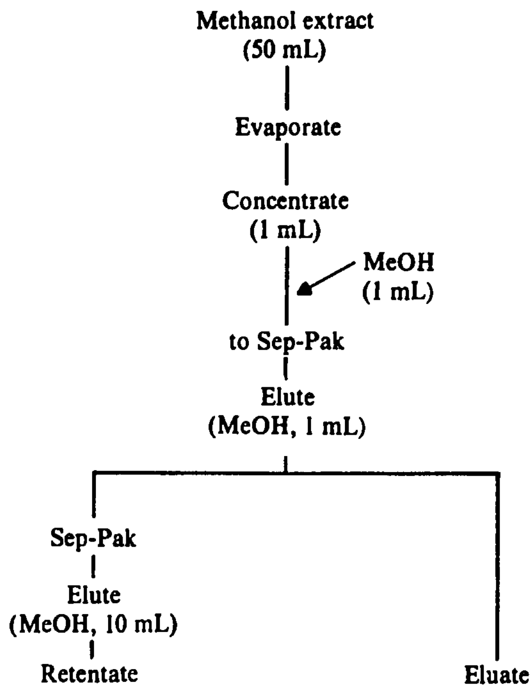

Figure 7. Reverse phase preparatory column fractionation of pearl millet methanol extracts.

of the molecule. An organoleptic study was therefore designed to test the ability of apigenin to support odor generation in methanol-extracted grits. Panel members were asked to use a continuous scale of 0 to 5 to rank the intensity of odor resulting from the wetting and drying of the four treatments listed in Table 2. Statistical comparison of the mean values for each treatment by least significant difference (LSD) demonstrated that the intensity of odors produced by apigenin-supplemented grits and grits reconstituted with their methanol extracts was not significantly different (Table 2). Further, both of these treatments produced significantly more odor than freshly milled controls.

Table 2. Least significant difference (t test) of odor-intensity ranking of millet grits.

Treatment	Mean[1]
Sequential wetting and drying	4.34a
Reconstitution with methanol extract	3.78b
Supplemented apigenin	3.00b
Freshly ground	1.00c

1. Mean score based on 10 replications rated on a scale of 0 to 5. Means with the same letter are not significantly different.

The data also show that the odor generated by wetted and dried unextracted grits was significantly more intense than that generated by either reconstituted or apigenin-supplemented grits. It may be that extraction of the grits by petroleum ether and methanol partially denatures the enzyme responsible for acting on the flavone portion of the substrate molecule. It is also possible that removal of the substrate from its native environment and re-addition in solvent (either as methanol extract or methanol solution of the pure compound) alters the ability of both enzyme and substrate to interact. In either case, the result is production of odor but at intensity levels below unextracted controls.

These results support the contention that off-odor production in ground pearl millet is the result of enzymatic action on the flavone portion of one of the characteristic C-glycosylflavones in the grain. Further work is necessary to determine the nature of the enzyme responsible and the structure of the odor-producing product.

Acknowledgments

This report is taken from Cereal Chemistry 63:403 (1986), where additional details are given. It is partly reprinted with permission of the Association of Official Analytical Chemists.

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Discussion

L.R. House: As you learn more about odor in pearl millet, do you feel that you can identify simple tests that can be used to help breeders apply a selection pressure against the odor?

R.C. Hoseney: Yes, but more basic work must first be done.

J.E. Cecil: In what part of the seed is the apigenin located?

R.C. Hoseney: In both the pericarp and in the outer parts of the endosperm.

J.M. Chitsika: Extracts with petroleum ether and chloroform gave a positive odor component, which would suggest that the component is not fat-related.

Can you suggest what the odor component is derived from or related to?

R. C. Hoseney: The odor component is not fat-related, but rather phenolic-related.

A.C. Moshe: Did you have a chance to look at the goitrogen aspects?

R. C. Hoseney: Yes, we have looked at that aspect. The work has been published.

M.I. Gomez: Is a preheat treatment beneficial for enzyme deactivation?

R.C. Hoseney: Heat treatments have other deleterious effects. Enzyme activity may be controlled by controlling moisture content.

Status of Sorghum Milling Technology at Rural Industries Innovation Centre, Botswana

S. Dinat[1]

Abstract

The paper is a brief account of the development of sorghum milling technology at the Rural Industries Innovation Centre (RIIC), Botswana, and the development of a marketing strategy. Technology transfer was carried out according to the needs of the end-user rather than the research center. Field results over a span of years resulted in further technical updating of the machinery. The paper also cites the problems encountered in researching and developing a rural-based technology, outlines the support structures required to implement a small-scale agro-industrial program, and expresses the need for a regional market outlook to support and strengthen technology development in the region. Trading results and throughput figures of a typical small commercial mill are analyzed to support the present parameters on machine size and performance, and a broad overview of the current milling industry in Botswana is given to indicate the impact of RIIC sorghum technology. The paper examines the potential for alternative uses of the machinery in relation to alternative uses of sorghum and millets.

Introduction

This chapter is an overview of the development of food processing technology at the Rural Industries Innovation Centre (RIIC) in Botswana. This technology has focused particularly on the sorghum dehuller. Despite RIIC's initial successes, the progressive development of technology is crucial. Also examined are the problems encountered in marketing a rural-based technology, the support structures required to implement such a marketing program, and the need for a regional market outlook.

The Botswana experience in sorghum milling technology has been extensively covered at previous workshops because the technology is as important to research centers as it is to the private sector. The rapid uptake of the technology has resulted in a great deal of interest from researchers, and numerous reports have highlighted the important role of technology intervention in the total grain production system.

The RIIC machine is a dry abrasive disc dehuller, adapted from the barley thresher modified by the Prairie Regional Laboratory (PRL). The principle is that of progressive abrasion of the outer layers of grains throughout the length of the dehuller. The dehuller is a semicircular metal barrel in which a set of abrasive, evenly spaced carborundum discs rotate clockwise against the grain. The discs' rotational speed of 1800-2000 rpm removes the grain husks with the aspiration fan located on the top of the barrel. Significant technical advances of the RIIC dehuller, including its aspiration system and trap door, facilitate both batch processing and continuous flow production. Critical design parameters include the special facing required on the abrasive discs which ensure that the grains are not crushed, the dimensions of the space inside the barrel, and the length of the barrel. Operational practices critical to quality and throughput are the air vent governors and the adjustable fan pulley that controls the rpm of the fan shaft.

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Dinat, S. 1992. Status of sorghum milling technology at Rural Industries Innovation Centre, Botswana. Pages 33–39 *in* Utilization of sorghum and millets (Gomez, M.I., House, L.R., Rooney, L.W., and Dendy, D.A.V., eds.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

RIIC's success in scaling down the PRL dehuller for use in a developing country responded to an expressed field need and fulfilled the basic national objectives of food security. Nonetheless, technology intervention as means towards development needs further study. One argument presently waged in Botswana is that technological development is unnecessary if the equipment can be purchased from developed countries. Those espousing this opinion claim that research is expensive and that present foreign reserves should be spent on imports. Recent experiences at RIIC, however, contradict this argument.

Y. Koga, in his observations of Southeast Asia, stated that if technologies are to be of any use, they must be perceived locally as being closely linked with the proper concerns. Rural communities are not likely to be interested in accepting a program unless it improves their living conditions.

Research indicates that the intervention of the RIIC dehuller in the postproduction system in Botswana has eased the burdensome task of pounding, as concluded by D. Narayan-Parker. Table 1 indicates the time saved by an average family in Botswana. Study also confirms that the RIIC dehuller has played a significant role in improving conditions for women and children in Botswana. The development of technology, however, must not cease with such initial success. Actual commercial use and increased marketing sophistication should continually and progressively adjust the hardware to meet the new demands.

Technical Developments

Responding to feedback from mill owners, RIIC undertook an Improved Rural Technology Program. The project, which took place from 1980 to 1982, was funded by the US Agency for International Development (USAID). The following was accomplished during the project:

- the impeller shaft bearing seats were relocated and tolerances on the fit were improved;
- the fan housing was redesigned to gain better access to the bearings;
- the stone shaft and spacer diameter tolerances were improved to reduce stone breakage;
- the trap door was fitted with a spring mechanism to reduce grain loss; and
- the mill building layout was redesigned.

These changes were incorporated into the existing mills, and new dehullers were manufactured to the new specifications and tolerances.

During 1985, the International Development Research Centre (IDRC) supported further development of techniques and systems at RIIC to further improve the performance of the small-scale mills in Botswana and to document the resulting technical changes.

The project's specific objectives were to:

- document the physical layouts of the mills;
- evaluate the economic and technical aspects of electric mills;
- reduce flour dust;
- develop and test a quick-release safety mechanism to disengage the engine from the mill;
- determine the effectiveness of the rubber lining;
- study the impact of a reduced barrel;
- study the pattern of stone wear against throughput; and
- update the existing Operator's Manual.

Summary of Results

1. Mill layout

Although suggested floor plants were issued by RIIC, most mills adapted existing buildings to suit their convenience. Mills located in rural areas using diesel power located their engines alongside the mill buildings and housed the mills independently of the grain stores and finished products stores.

Table 1. Saved time redistribution by an average Botswanan family using an RIIC dehuller.

			Saved time redistribution		
Family member	Food preparation time (h)	Time saved (h)	Household activity (5)	Production activity (%)	Other (%)
Woman	4-6	2.5	57	41	2
Child	3	2	31	50	19

It is interesting to note that the larger commercial mills have incorporated several novel production features, such as dust trap boxes, gravity feed, and electric motors. The two largest mills have opted to operate under large roof-sheds. The project report described the mill in Serowe as resembling a lunar landing module!

2. Evaluation of electric motors

The rapid rural electrification program initiated by the Government of Botswana has made the use of electric motors in the larger villages possible. The initial design specified the use of a 22 hp diesel engine, though calculations indicated that only 15-16 hp was required. Although the inefficiencies of the engine and power losses in the intermediate shaft warranted the use of a larger engine, it was discovered that a 15 hp, 3-phase, 1480 rpm engine provided sufficient power for the dehulling operation. Two sites were outfitted with 11 kW motors and independent meters for measuring usage.

Present data reveal that with a combined system using a 11 kW motor driving both the hammermill and dehuller directly (not using an intermediate shaft), an average of 3.888 kW h^{-1} were consumed to dehull and mill 218 kg of sorghum. The actual cost compared very favorably to the milling cost using diesel power.

The capital and recurrent costs for the two power sources further support the use of electrical motors where possible. RIIC is presently collecting similar data for independent drive systems using 9 kW and 3 kW motors.

3. Progress on flour dust reduction

It is estimated that 2-4% of all throughputs are lost. The main leakages occur at the three points listed below.

a. *Dehuller*

- Suction channel
- Fan housing outlet connection
- Dehulled grain outlet sprout
- Air vent gauze
- Feed hopper

Design alterations were made to address dehuller leakage through a major design review. Spillage was further reduced by changing the relative heights of the dehuller and hammermill to facilitate gravity feed from the dehuller to the mill. Wooden molds are now used to increase tolerances on the fit of the extension pipes.

b. *Cyclone.* The new cyclones are fitted with an additional sleeve which reduces the flow of heavy particles escaping through the exhaust.

c. *Hammermill.* The hammermill is noisy and dusty because of its design. RIIC advises mill owners to reduce the air inlet screen to avoid grain loss through hammering action. Data from a mill operating a roller mill is being collected.

4. Quick-release mechanism

According to the mill layout, the diesel engine is located adjacent to the mill, requiring the mill operator to walk around the building to disengage or switch off the power. A simple level mechanism was therefore developed to simplify this situation with galvanized piping bent into a "Z" shape. The vertical part of the bent tube is attached to angle iron brackets in the wall of the engine room; and the lower horizontal length attached to the clutch lever is bent over the top of the dehuller. The operator pushes the pipe, which pushes the clutch lever and disengages the engine.

The total cost of the mechanism, which has been tested at one mill for a period of 6 months, is 100 Pulas. Despite informing mill owners on the use of the disengaging gear, little response was received.

5. Barrel sizes

A total of six units were manufactured with the following variations.

- One standard-size dehuller without lining.
- Two standard-size dehullers without lining (reduced barrels).
- One standard-size dehuller with nonrubber lining.
- One standard-size dehuller with linatex lining.

a. *Dehuller without lining (DWL).* Tests were carried out on the two DWLs after processing 139 kg in one location and 930 kg in another location on the first DWL, and 137 kg in one location and 830 kg in another location on the second DWL. Both machines also processed 800 kg maize. The following conclusions were drawn.

- Total dehuller performance was not affected by nonlining.
- Maize dehulling improved (less breakage due to the larger gap).
- Noise level was high.
- Greater leakages through the trap door and side wall edges was evident.
- "Shine" on the trough and markings in line with stone were observed.
- The outside wall of the trough became "pimpled" and hot.
- Rubber lining appeared advantageous.

b. ***Dehuller reduced barrel (DRB).*** Only preliminary tests were carried out as a result of reluctance of participating mill owners due to the low extraction rates. Conclusions from the preliminary tests indicate the following.

- The trough was extremely hot.
- Extraction rates were in excess of 75%.
- Performance was unsatisfactory.

c. ***Dehuller with nonrubber lining (DNL).*** The locally acquired rubber lining was nonvulcanized and unhardened, as opposed to the lining presently available, at about the same price. The lining was attached to the trough with standard adhesive. After a very brief period, the following conclusions were drawn.

- The lining was removed after processing 5 t material.
- The lining bubbled and lost adhesion.
- Performance was unsatisfactory.

d. ***Dehuller with linatex lining (DLL).*** A lining commonly used in the mining industry was recommended by the engineering workshop producing the dehuller. Linatex is produced from pure Malayan rubber by a special cooling process which eliminates particle breakdown, and is commonly used on conveyer belts carrying gravel and sludge. Its resistance is higher than that of other rubbers. However, the lining tore off the trough after processing 35 t and is therefore not recommended.

6. Stone wear patterns

Dehullers with and without the rubber lining were stripped to weigh each stone and compare it with its original weight (Table 2). Both dehullers processed approximately 140 t grain (mainly red varieties). The study revealed the following.

- The original masses of the stones varied.
- Stone wear was insensitive to position in the barrel.
- Stone wear on the unlined dehuller was 40% greater.

Table 2. Dehuller stone wear patterns.

	Mass of lined dehuller stones (kg)			Mass of unlined dehuller stones (kg)		
Stone	New	Used	+/-	New	Used	+/-
1	1.95	1.60	0.35	1.95	1.54	0.41
2	1.95	1.95	0.20	1.89	1.65	0.24
3	1.95	1.85	0.10	1.96	1.66	0.30
4	1.85	1.80	0.05	1.89	1.75	0.14
5	1.90	1.80	0.10	1.98	1.80	0.18
6	1.96	1.75	0.21	1.98	1.75	0.23
7	1.85	1.85	0.00	1.85	1.66	0.19
8	1.90	1.80	0.10	1.95	1.85	0.10
9	1.90	1.70	0.20	1.96	1.75	0.21
10	1.85	1.60	0.25	1.94	1.89	0.05
11	1.90	1.85	0.05	1.96	1.75	0.21
12	1.90	1.85	0.05	1.91	1.75	0.16
13	1.90	1.70	0.20	1.85	1.65	0.20
Total	24.76	22.90	1.86	25.07	22.45	2.62

Although the stones had worn down by 7.5% (lined dehuller) and 10% (unlined dehuller), the abrasive qualities were acceptable to the operators. Extraction rates of 85-88% were obtained.

7. Progress on Operators Manual

Preparation work regarding translations, photographs, exploded views, and layout has been completed for the updated manual.

Present Distribution of Technology

The existence of the sorghum milling industry in Botswana is due entirely to the introduction of the dehuller. To a large extent, therefore, the industry is dependent on the continuing support of RIIC. The milling industry is one of the few small-scale food industries in Botswana. Presently, there are 30 milling operations in Botswana, scattered mainly in the east of the country. Initial mill sales were concentrated around farming areas, anticipating a linkage between crop production and processing. The first generation of sales were intended for service milling, primarily processing for domestic use. However, the popularity of the end product and urban demand for a neatly packaged grain flour encouraged commercial milling in the larger villages and the peri-urban areas.

The pattern of sales in Botswana from 1979 to 1987 reveals three different phases in the marketing strategy: a gradual upward trend, a plateau, and a gradual decline. A total of 50 dehulling units have been sold nationwide, and six others have been ordered. Export sales outstripped projections, with unprecedented sales to South Africa. The lesson gained is recognition of the fact that had the export market not come onstream in 1984, it would have been difficult to transfer the manufacturing technology to the private sector. To a large extent, therefore, increased production assisted investment. Initial market studies predicted a total national market of 10 units only, against a total research investment of US$ 250 000.

If and when African governments can support research, economists are certain to question the payback of technological research. It is thus imperative that the market be extended throughout the SADCC region, making research and production economically feasible.

Marketing Techniques

At project inception, RIIC did not have a marketing plan in hand. The plan was born out of expedience and was shaped by the market. The primary technique was defining the target market and establishing a strong bond between the product and the client.

In a rural market, the use of fancy catalogs and highly detailed technical specifications is questionable. Participatory demonstration followed by heavy extension input is more effective for marketing in rural communities.

Having defined the market, RIIC focused the technology on farmers by attending agricultural shows, during which the machine was promoted. The agricultural shows also provided a venue for demonstrating the machine to small-scale industrialists by presenting economic scenarios, sample cash flows, payback periods, and rates of return for the milling industry.

To support its marketing efforts, RIIC initiated and directly managed the user's group, and also managed a sorghum mill itself. The direct contact within the industry provided healthy information flow and data collection. RIIC also provided training to new mill owners as an incentive to budding entrepreneurs.

To encourage export markets, RIIC used every opportunity to discuss the technology in journals circulated by aid agencies, and information specialists were asked to write about the sorghum milling industry in Botswana. Further incentives involved appointing local companies as export agents to assist in regional marketing. The RIIC dehuller was submitted at an international competition of mechanical designs from the Third World. The competition, which was held in Italy, awarded a prize to the dehuller, and this international recognition further generated sales.

Direct contact marketing techniques were applied, and specific personnel were designated to deal directly with the flood of requests. Staff members were also responsible for establishing a rapport with national financial institutions. Reservations must be expressed for the direct marketing approach adopted by RIIC, since they may only be applicable to Botswana's unique social network, and thus may not function in more fierce economies or more populous nations.

Alternative Uses of the Sorghum Project

Technical description

The proposed project will be divided into three phases; (1) a desk study on uses of traditional grains, especially sorghum; (2) a product development phase; and (3) a pilot production phase to test the market.

1. Desk study

The desk study is scheduled to begin within the first quarter after the approval of the project. Current plans include collaboration with the national agricultural research system and SACCAR in Sebele, as well as the Post-Harvest Food Industry Advisory Unit, (PFIAU) and the SADCC/ICRISAT Food Nutrition Unit in Harare. It is anticipated that Botswana Foods Limited will play a key role in implementing this activity. The overall objective of the desk study is to collect and document information required to carry out the project. Major components of the study, which should take about 2 months, will include the following.

- Documentation and collection of information necessary for developing the products, including the nutritional values of major sorghum cultivars of Botswana and the southern African region.
- Examination of the degree of suitability for the food products under review.
- Provision of resource data to assist millers in their product development efforts.

2. Product development

a. ***Sorghum meal malt for porridge making.*** The equivalent of this proposed product is presently imported into Botswana from South Africa under the trade name Maltamella. It is highly nutritious and is usually served as a breakfast dish. The proposed study will explore methods of developing a dry malt based on sorghum, a detailed project profile, blending formulae, and testing of pilot batches. It is estimated that development work on this product will take about 4 months.

b. ***Malt for traditional beer brewing.*** This product is currently produced by Shapane Malt Factory in the Tuli Block area, although it is inferior to malt imported from South Africa. The study will develop production methodology of malt at a small-scale level. It is hoped that research and development will document choice of cultivars used for malt production. Methods applied (i.e., soaking periods, fermenting time, drying, and optimum milling rates) to produce a product of high quality on batch-controlled systems should also be studied. Product development is estimated to take 4 months.

c. ***Instant beer powder.*** The rationale behind the development of traditional beer brewing technology stems from the fact that large urban breweries have largely replaced localized village brewing, a traditional income-generating activity for rural women. This study will document methods of developing beer powder equivalent in quality to King Korn® beer powder. The information package should include choice of grain, testing procedures, and acidity/alkalinity tolerances (including formulas). This product is geared for production in batch quantities. Product development should take at least 6 months.

d. ***Related products.*** A brief feasibility study will be effected to investigate opportunities for small-scale industries to produce extruded snack foods from sorghum. The potential of other uses of extruders will also be carried out. It is expected that the study will document other sorghum products hitherto manufactured in Botswana by various food manufacturing agencies. The study will then make recommendations on products that can/should be produced in Botswana by the milling industry. Advice will be needed for uses of the byproduct bran. Three months will be needed to complete this part of the project.

3. Pilot production/market tests

The implementation and timing of this phase will coincide with the development of each of the above products. Pilot batch production runs will be undertaken in close collaboration with Boiric (Pvt) Ltd. Packaged samples will be introduced to the market on an experimental basis at this stage. Consumer reaction to the products will be documented, and final production methods and product quality control levels will be finalized, where possible, through involvement with other food manufacturing agencies. All aspects of product marketing will then be investigated. Costing analyses for each of the products will be formulated to ascertain margins.

Discussion

A.C. Moshe: Concerning alternative products, don't you think processing will be expensive and packaging will be difficult?. Why not use nutritious foods available in the home?

S. Dinat: Flour provided for drought relief programs is unsuitable for babies. Home-level additives such as milk and oilseeds is extension-oriented and will be borne in mind during the study.

M. Mudimbu: I have three questions.
1. What is the quality of meal with regard to color or taste?
2. What is the byproduct and what is this used for ?
3. What is the price of sorghum meal compared with maize meal?

S. Dinat:
1 The quality of meal depends on the cultivar dehulled and the method of dehulling. The coarseness depends on the milling screen and can be adjusted to customer preference.

2. In Botswana, customer preference is for coarse flour. The byproduct is bran, which is used extensively by cattle farmers as feed.
3. The prices of sorghum meal and maize flour are similar. Sorghum meal sells for Tebe 48-52 kg^{-1} compared to maize flour which ranges from Tebe 50 to Tebe 54 kg^{-1}.

F.E. Sauwa: At what weight should the grinding stones be changed?

S. Dinat: About 1.5-1.6 kg.

R.E. Schaffert: What is the cost of the Tshilo dehuller?

S. Dinat: About US$ 2000.

T. Rukini: Is there any need to reduce the size of the dehuller in order to cater for sparsely populated rural areas with low communal areas?.

S. Dinat: From the Botswana experience it appears that a smaller dehuller is not needed. Further, I see no rationale for developing a small dehuller with no aspiration system since the process will be incomplete.

Sorghum Malt/Adjunct Replacement in Clear (Lager) Beer: Policy and Practice in Nigeria

O.A. Koleoso and O. Olatunji[1]

Abstract

A sudden decline in foreign exchange coupled with the desire for self-reliance caused the Nigerian government to change its policy of gradual and partial substitution of imported industrial raw materials to one of total and immediate substitution. The effect of this policy on the brewing industry, which had imported its entire barley malt requirement, was substantial. The need for a local substitute became imperative when the ban on barley malt import became effective on 1 Jan 1988. Prior to this decision, various laboratory, pilot plant, and commercial tests had established that sorghum malt or grits could be used for brewing. Appropriate malting and brewing procedures for sorghum were established by the Federal Institute of Industrial Research, Oshodi, using 25%, 50%, and 100% substitution. Beers made with malted sorghum were tested and compared with existing brands made from barley malt. The efforts of the Federal Institute of Industrial Research, the Federal Ministry of Science and Technology, and various brewing houses to comply with the objective of import substitution are discussed.

Introduction

Since the establishment of its first brewery in 1949, Nigeria's brewing industry has witnessed tremendous development. The rapid growth of the Nigerian beer industry typifies the nation's industrial development policy of import substitution. The strategy requires high import content of industrial inputs, characterized by dependence on imported raw materials, reliance on foreign research and development, low value added to local input, high production cost, and high protective tariffs. Of 52 approved Nigerian breweries, 34 are in operation, producing about 40 brands of beer—a total of 18.3 million hL. At full capacity, the breweries annually spent about Naira 495 million to import barley malt.

Policy

The sudden decline in foreign exchange earnings left the Government with no alternative to introducing programs emphasizing reliance on the use of local raw materials as well as the reduction of importation of finished goods. As part of this strategy, a Structural Adjustment Programme (SAP) was introduced.

In 1987, the Government took the following decisions regarding the beer sector.

a. Importation of barley malt will not be allowed as of 1 Jan 1988. All breweries and malt-based industries should convert to the use of sorghum or other local cereal substitutes.
b. Enzyme importation will be allowed until 1 Jan 1990, when malting facilities should be established and adequate quantity of the right variety of malted sorghum produced in order to effect a total changeover to local raw material in beer brewing.

Because the brewing industry is one of the most successful in Nigeria, these governmental decisions led to huge increases in raw material importation (especially of barley malt, the major raw material).

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Traditionally, barley is the only cereal malted for production of lager beer in Nigeria, and the amount of foreign exchange involved is very high (Naira 500 million). The Federal Institute of Industrial Research envisaged the problems posed by high dependence on imported raw materials several years ago, and in 1973 embarked on systematic screening of local varieties of cereal grains (mainly sorghum, millet, and maize) to evaluate their malting characteristics.

Sorghum Grain and Malt

Sorghum displays a unique agricultural adaptability to a world in need of more food. Traditionally, Nigeria has employed sorghum in both malted and unmalted forms in a wide variety of porridges and beverages. The three important local brews made from sorghum and popularly consumed by the rural populace are known as *pito*, *burukutu*, and *otika*.

Our initial investigations in the Institute showed that sorghum has better malting characteristics than the other cereals tested (maize, millet, and rice). Other advantages of sorghum are its availability and low production cost, as well as its chemical properties and high malting quality. The production of sorghum was estimated at 4.54 million t in 1986 and 5.45 million t in 1987. The projected estimate for 1988 is 6.54 million t. These figures are considerably higher than those for the other cereal grains.

About 200 varieties of sorghum were screened. The important parameters considered during screening included changes in nitrogen content, protease activity, diastatic activity, extract yield, and cyanide and tannin content. Based on these parameters, sorghum variety SK 5912 was found to be the most suitable after screening tests in 1980. Other varieties have since been developed and screening exercises are ongoing.

Table 1 compares the physical and chemical analyses of sorghum malt and barley. Both grains exhibit similarities in many of the parameters considered. However, the temperature of gelatinization of sorghum starch is higher than that of barley, and the malt has lower extract yield and diastatic power than barley malt.

Table 1. Comparative analysis of sorghum malt and barley malt.

Parameters	Sorghum malt	Barley malt
Moisture (%)	2-5	1.6-2.0
Total nitrogen (%)	1.25	1.48-1.60
Soluble nitrogen (%)	0.54	0.5-0.7
Malting loss (%)	11-15	6.0-15.0
Extract yield (L kg^{-1})	295	279-400
Diastatic power (L)	38	33-63

Malting Process

The malting of sorghum grains is similar to the malting of other grains. It starts with the steeping of precleaned grains in water for a specific number of hours. The steep-ripe grains are transferred to germination beds and kept for 6 days. During malting, the endosperm of the grain is degraded by enzymes mobilized during steeping. By the end of germination, the degradation of the food reserve has progressed sufficiently. The malt is then kiln-dried and stored.

Research Findings in Brewing with Malted Sorghum

Our preliminary investigations focused on the gradual substitution of sorghum malt for barley malt to produce lager beer. Both laboratory and pilot production trials were successful. The encouraging results prompted this the Federal Institute of Industrial Research, Oshodi (FIIRO) in 1984 to embark on commercial production trials of lager beer from blends containing 25% and 50% sorghum malt. These trials resulted in the production of the popular "Femos Special" and "Femos Extra" lager beers. Analyses of the two brands are presented in Table 2.

Table 2. Chemical analyses of Femos Beers.

Parameters	Extra	Special
Color	5.0	10.25
Specific gravity (20°C)	1.00351	1.0034
Apparent extract	0.90	1.25
Alcohol by weight (%)	4.11	4.4
Real extract (%)	2.79	3.33
Extract of original wort (%) (calculated)	10.81	11.86
Real degree of fermentation (%)	74	71.92
Apparent degree of fermentation (%)	92	89.46
Iodine reaction	Negative	Negative
pH of beer	3.75	4.4
CO_2 by weight	0.75	0.58
Air (mL)	1.48	-
Foam collapse rate	80	-
Isohumulone (ppm)	19	19

The spontaneous and general acceptability of the blended beer had a dramatic effect on the Nigerian brewing industry. Recently a commercial brewery (Jos International Breweries) produced a lager beer called "FIIRO" on a pilot scale using 100% sorghum malt.

The milling of sorghum malt is an important step in the process of obtaining a particle size that will give a high extract yield and short lautering time. Roller mills were found superior to other types of milling equipment. Three mashing procedures were employed to evaluate the physical, chemical, microbiological, and sensory quality of each sample. The most acceptable samples were those most similar to existing commercial brands. Finally, 18 cartons of lager beer brewed with 100% sorghum malt were produced.

The qualities of the beers produced from the three mashing procedures were compared (Table 3). The sensory evaluation of the 100% sorghum beer and the existing barley malt beer in the market is presented in Table 4. In addition, samples were distributed to ma-

Table 3. Comparative analysis of sorghum malt beer and barley malt beer.

	Sorghum	Malt	Lager beer	Barley malt lager beer
Original gravity (p)	11.6	10.6	11.0	11.2
Alcohol content (wt %)	3.95	3.7	3.95	4.1
Color (EBC)[1]	6.0	6.0	6.0	7.5
pH	4.6	4.53	4.16	4.2
Isohumulone (IBU)[2]	17	19	16	20.2
CO_2 content (wt %)	0.49	0.49	0.53	–
Total haze (form units)	0.31	0.49	0.50	0.7
Turbidity (EBC)	0.4	0.5	0.50	Max 0.8
Foam stability (sec)	130	130	130	–
Total acidity (as lactic acid)	0.17	0.17	0.17	–
Microbiological examination	None	None	None	–

1. EBC = European Brewing Convention, methods of analysis.
2. IBU = International Bitter Units (According to EBC specification).

Table 4. Mean value of the scores from comparative evaluation of FIIRO Lager Beer and market brands.

Trade names	Star	Rex	FIIRO II	FIIRO III	Merit	Gold
Color ratings	2.80 Like very much	3.01 Like moderately	3.60 Like moderately	3.53 Like moderately	3.73 Like moderately	2.73 Like moderately
Taste ratings	3.40 Moderately pleasant	3.00 Moderately pleasant	3.60 Moderately pleasant	3.53 Moderately pleasant	5.33 Neutral	3.00 Moderately pleasant
Flavor ratings	2.80 Very desirable	3.67 Moderately desirable	3.33 Moderately desirable	3.20 Moderately desirable	5.07 Nuetral	3.07 Moderately desirable
Impact/strength ratings	3.67 Moderately	3.60 Moderately	3.80 Moderately	3.40 Moderately	4.07 Slightly	3.07 Moderately
Overall acceptability ratings	2.80 Like moderately	3.27 Like moderately	3.60 Like moderately	3.40 Like moderately	5.73 Neutral	3.40 Like moderately

jor breweries around the country for analysis and comments. Samples were also sent to the Ministry of Science and Technology and to individuals for sensory evaluation. The results show that sorghum malt beer is acceptable and comparable to barley malt lager beer. Comments comparing the taste, color, and smell of sorghum beer with existing commercial beer were generally favorable, as shown below.

- "The taste of the beer is nice, but it has the odor of sorghum malt."
- "Very good beer! FIIRO and indeed Nigeria should be proud of the product. I would not hesitate to buy the brand even at the present high cost of other brands. I commend the effort."
- "After consuming the beer, I was convinced that there can never be any argument that sorghum malt is inferior to barley malt in the production of beer. The taste is excellent and can compete favorably with any other type of imported beer."
- "In my opinion, the beer is quite potent and tastes generally like other beers."
- "An excellent beer and a wonderful effort by FIIRO."

Sorghum Adjunct Malt in Beer Brewing

Maize and sorghum grits are currently used as adjuncts in virtually all Nigerian breweries. Levels range from 25% to 50%. One of the biggest breweries, Guinness Nigeria Limited, carried out a few production runs with 100% unmalted maize grits in 1987. The beer is called "Merit". Other industries have also tried various substitutions for sorghum malt to brew new brands of beer. "Kings", for example, uses 50% sorghum malt as a substitute, and "Mayor" uses 65% sorghum malt substitution. Other industries have brewed with 100% sorghum malt. Some of these beers have been marketed while others are still undergoing testing.

Comparative Assessment of Malted and Unmalted Sorghum in Beer Brewing vizà-viz Barley Malt

The current annual requirement of barley malt is 353 000 t, assuming all breweries are operating at their full capacity of 18.3 million hL. The estimated cost of this barley malt is 495 million Naira in foreign exchange. It is estimated that the use of 100% sorghum grits would require 335 665 t, a value of 469 million Naira. However, an additional 242 million Naira is required in foreign exchange for enzyme importation.

It is pertinent to note that with the present varieties of sorghum, enzymes are needed to saccharify the starch in the grain to produce beer with good body and reasonable alcoholic strength. With good barley malt, the use of external enzymes is unnecessary. The current practice of using high percentages of adjuncts, however, involves the use of external enzymes. Although the use of 100% sorghum grits or malt necessitates the importation of enzymes, the value required for malted sorghum is small compared with that of other unmalted sorghum or imported barley malt. During the malting of sorghum, the necessary enzymes are produced, but the amount is insufficient for complete saccharification of the starch in the grains.

The slight reduction in the diastatic enzymes of sorghum poses a challenge to breeders. Brewers expect breeders to develop sorghum varieties that will produce larger amounts of enzymes characterized by reduced oil and protein content but increased testa.

Prospects and Constraints of Production Systems

The existing equipment in many Nigerian breweries is adequate for brewing lager beer from sorghum. However, a few breweries require modifications.

a. **Sorghum Grits.** The equipment needed for converting sorghum to grits for beer brewing exists in Nigeria. The quality of the grits falls short of brewery requirements in a few cases. However, the mills have started to modify their equipment to adjust to the impending market demands.

b. **Malted Sorghum.** Although commercial malting of sorghum is under way, the existing capacity for sorghum malt satisfies only about 2% of requirements and consists mainly of the floor type. Efforts are geared towards increasing the capacities of existing plants and to set up new plants as the need increases. Joint venture proposals are also under consideration by some breweries for modern industrial malting facilities. Rather than encouraging this, I prefer to support the upgrading and multiplication of facilities currently in use, as this will more effectively spread the benefits of the process.

c. **Mashing.** The mashing process in brewing is accomplished with either of two methods: decoction or infusion. Most breweries prefer the decoction method, which is suitable for both malted and unmalted cereals. The infusion system, which requires external workers for handling unmalted cereals, requires little plant modification.

d. **Filtration.** Brewing with local cereals, especially unmalted cereals, requires the use of mash filters. Many of the breweries already using high levels of local cereal (maize, sorghum, or rice) have already introduced the use of mash filters. No serious technical problems are envisaged for the inclusion of mash filters in the breweries where they are absent.

Market Testing and Acceptability

Both brands of Femos were market-tested to confirm nationwide acceptability. Criteria for acceptability were taste, flavor, aroma, after-palate strength, aftereffect, clearness, and foaminess. Taste evaluation was carried out in Lagos, Jos, Makurdi, Port Harcourt, Aba, and Benin. The predominant local beer was used as the reference lager in each area, thereby allowing for local taste preferences. The consensus was that the sorghum lagers were quite acceptable.

Commercial production of 100% sorghum malt beer is anticipated in many Nigerian breweries, and some are already producing it. One of the commercial breweries recently reported:

"The note is to inform you that our brewery has achieved the 100% replacement of barley malt with sorghum malt. It is worth noting that the exercise was done commercially without any replacement in our present machinery set-up, particularly the filtration device (lauter tun). In our commercial brew we observed that sorghum malt mash filtered faster than our usual barley malt mash."

It appears that marketing will not be a problem. The use of unmalted cereals like sorghum might pose slight problems since consumers were able to differentiate the beer made from unmalted maize (Merit) from the other brands. With aggressive advertisement, however, consumer acceptability of beer from unmalted sorghum should be forthcoming.

Cost

The cost of the technological changeover from barley malt to sorghum malt is minimal and within the budgets of all the breweries. In fact, many breweries may not need to buy additional equipment. It is unlikely that the change will increase the price of beer. Our expectation is that in time the price will gradually come down.

Conclusions and Recommendations

It is clear that sorghum, either malted or unmalted, can be used for the production of lager beer. Malted sorghum has an advantage in that it conforms to existing brands, and low foreign exchange is involved in the importation of additional enzymes.

The change to the use of locally produced sorghum from imported barley will lead to huge savings in foreign exchange and create new markets for sorghum. Improvements in related agricultural and technological activities will create more jobs and give Nigerians the pride of consuming what we produce ourselves.

Breeders should intensify their sorghum improvement programs by selecting for sufficient diastatic power and increased testa to meet the needs of the brewing industry.

Traditional Technologies in Small Grain Processing

S.Z. Mukuru[1]

Abstract

Traditional small grain (mainly sorghum and millets) producers in the semi-arid tropics of Africa and India have developed simple but effective technologies to process their grains. These technologies are variable, depending on the types of grains produced. In general, traditional grain-processing technologies are used for cleaning, dehulling, and grinding grain into flour. Farmers in the southern highlands of Uganda and neighboring areas, where high-tannin sorghum types with soft endosperm grains are extensively grown, have developed a unique traditional technology of processing high-tannin grains before they are consumed. This technology involves mixing high-tannin grains with wood-ash slurry, followed by soaking the grains in water overnight. The grains are then germinated for 3 to 4 days, followed by drying in the sun, cleaning, and grinding into flour. This treatment effectively detoxifies the grain and improves its nutritional quality to the level of low-tannin grains. In this paper, traditional cleaning, dehulling, and grinding into flour of small grains are reviewed briefly; the traditional technology of processing high-tannin sorghum grains is described; and its effectiveness in improving nutritive quality is reported. The applicability of the technology to a range of sorghum grains is also discussed.

Introduction

Sorghum and millets are the most important small grains for millions of resource-poor farmers in the semi-arid tropics of Africa and India. These farmers have developed simple grain-processing technologies that significantly improve the acceptability and quality of these grains. Traditional technologies are used to clean, dehull, and grind small grains into flour. In the southern highlands of Uganda and neighboring countries, a unique traditional processing technology was developed for the high-tannin sorghum produced exclusively in these areas. The technology, which involves treating the grain with wood ash, soaking in water, and germinating the grain is very popular and is believed to improve the nutritional quality of brown-seeded high-tannin sorghum grains. In this chapter, traditional technologies for dehulling, grinding, and processing high-tannin sorghum grains are reviewed. The effectiveness of these technologies in detoxification and improving nutritional quality are investigated.

Traditional Small Grain Dehulling and Grinding

Traditional small grains (sorghum, pearl millet, and finger millet) are hand harvested, dried, and stored in traditional storage structures. Small quantities are regularly hand threshed, cleaned, winnowed, and sometimes pounded to remove tight glumes. Sorghum grain may be dehulled before grinding, depending on the types of grains produced and the foods prepared.

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Although sorghum is not dehulled to produce *towo* in certain localities in Nigeria, dehulling the grain for *ogi* preparation is usually carried out because it is generally accepted that dehulling improves the *injera* quality (Gebrekidan and Gebrehiwot 1987). The highly corneous grains are much easier to dehull and give higher grain recovery rates. In general, white-seeded high-tannin types that also have a soft endosperm are not dehulled (Mukuru et al. 1982).

Traditional dehulling generally involves pounding the soaked or damp grain in a wooden mortar with a wooden pestle and winnowing to separate the dehulled grain from bran (Eggum et al. 1983, Mitaru et al. 1983, Mukuru 1986). In Mali and Burkina Faso, the grain is dehulled before it is made into *to* (Boling and Eisener 1982). In India, on the other hand, sorghum is dehulled in a stone mortar with a wooden pestle after moistening (Murty et al. 1982).

Cleaned whole or dehulled grain is ground into flour on traditional grinding stones—a small flat stone on a larger rectangular one. The grain must be clean and sufficiently dry to produce flour of acceptable quality. The grains are crushed into flour by the constant friction of the two stones. In Nigeria (Obilana 1982) and Botswana (Boling and Eisener 1982), dehulled grains are pounded in a wooden mortar with a pestle and sieved at intervals to produce flour. For many people in rural areas where mechanical grinders are unavailable and where prices charged for grinding are prohibitive, the traditional method is still used.

Traditional Processing of High-Tannin Sorghum Grain

Brown-seeded, high-tannin sorghums are grown both for food and drink in various parts of Africa where the bird (*quelea*) problem is severe because these types are least preferred by birds. High-tannin sorghums also have an agronomic advantage over low-tannin types because they are resistant to grain molds and preharvest germination (Harris and Burns 1970a, Harris and Burns 1970b). The disadvantage of brown-seeded sorghum grains is their antinutritional character. When used as food, the tannins in the grain bind up enzymes and proteins in the digestive tract causing low digestibility (Hahn et al. 1984).

Mechanical and chemical methods have been developed to overcome the antinutritional effects of high-tannin grain (Chibber et al. 1978, Mitaru et al. 1983, Price et al. 1979, and Scheuring et al. 1982), but these are expensive and impractical for resource-poor farmers. In the southern highlands of Uganda where high-tannin sorghums are consumed, a popular processing technology has been developed.

Processing Technology

First, brown-seeded, high-tannin sorghum grains are cleaned and winnowed to remove loose dirt, glumes, and other particles. The cleaned grain is then thoroughly mixed with wood ash slurry, which is obtained by dissolving one part wood ash (weight) to one part water (volume). Approximately 150 mL of wood ash slurry is sufficient for 1 kg of grain. The treated grain is transferred into a grass basket and soaked in water overnight (12-15 h). After soaking, the grains are well drained and covered in grass for 3-4 days until germination when the radicle is about 2 cm long. Germinated grain is then spread in the sun to dry. After drying, it is cleaned by pounding in a wooden mortar with a pestle to shake off loose wood ash dust and to break the dried radicles off the grain. After winnowing, the grain is ready to be ground into flour on traditional grinding stones. The flour is generally used to prepare traditional beverages called *obushara* (nonalcoholic) and *omuramba* (approximately 2.8% alcohol).

Effect of Traditional Processing on Nutritional Quality

Traditionally processed and unprocessed grains of a brown-seeded, high-tannin local sorghum cultivar were obtained from southern Uganda in 1986 and analyzed at Purdue University for tannin content, percent protein, and in vitro protein digestibility. Grains of 954 063 (low tannin) and BR 64 (high tannin) were also analyzed as controls. The results, shown in Table 1, clearly demonstrate the effectiveness of the traditional processing technology in improving nutritional quality of high-tannin grain. Traditional processing significantly reduced tannin content from 6.88% to 0.04%, which is not significantly different from that of 954 063 (a white-seeded low-tannin sorghum), and significantly improved protein content and in vitro protein digestibility to the level of that of the low-tannin 954 063 control.

Traditional beverages prepared from processed grains, both alcoholic and nonalcoholic, were also obtained from southern Uganda and analyzed for in

Table 1. Tannin content, percent protein, and in vitro protein digestibility of traditionally processed and unprocessed grains of a high-tannin local sorghum from Uganda compared with controls 954 063 (low tannin) and BR 64 (high tannin).

					In vitro protein digestibility – uncooked (%)		
						Traditional beverages	
Sorghum	Treatment	Grain color	Tannin (CE)	Protein (%)	Grain	*Obushara* (nonalcoholic)	*Omuramba* (alcoholic)
Local sorghum	Unprocessed	Brown	6.88	9.12	15.9	-	-
	Processed	Black	0.04	10.47	66.6	46.2	73.2
954 063	Unprocessed	White	11.41	64.9	-	-	-
BR 64	Unprocessed	Brown	-	-	-	-	-

CE = Catechin equivalent.

Table 2. The effect of 0.01 NaOH and three wood ash treatments on grain color, percentage of dry matter loss, and tannin contents (CE) of grains of a high-tannin local sorghum from Uganda.

Treatment	Grain color	Dry matter loss (%)	Tannin content	Reduction in assayable tannins (%)
1. Unprocessed grain	Brown	0	9.284	0
2. Water	Brown	3	3.628	61
3. 0.01 NaOH	Black	4	0.224	98
4. Ash filtrate	Black	4	0.360	96
5. Ash residue + water	Black	4	0.247	97
6. Ash slurry + water	Black	4	0.336	96
7. Water + germination	Brown	16	2.640	72
8. 0.01 NaOH + germination	Black	17	0.072	99
9. Ash filtrate + germination	Black	12	0.128	99
10. Ash residue + water + germination	Black	16	0.080	99
11. Ash slurry + water + germination	Black	16	0.048	100
12. Traditionally processed	Black	18	0.052	99

Treatments as follows:

1 = Unprocessed grain.
2 = Grain soaked in water for 12 h.
3 = Grain soaked in 0.01 NaOH for 12 h.
4 = Grain soaked in wood ash slurry filtrate for 12 h.
5 = Grain mixed with wood ash slurry residue and soaked in water for 12 h.
6 = Grain mixed with wood ash slurry and soaked in water for 12 h.
7 = Same as (2) and germinated for 2 days in an oven at 30°C.
8 = Same as (3) and germinated for 2 days in an oven at 30°C.
9 = Same as (4) and germinated for 2 days in an oven at 30°C.
10 = Same as (5) and germinated for 2 days in an oven at 30°C.
11 = Same as (6) and germinated for 2 days in an oven at 30°C.
12 = Traditionally processed grain from Uganda.

vitro protein digestibility at Purdue. Percent protein digestibility of *obushara* was lower than that of the processed grain, while that of *omuramba* was much higher. It has been reported that sorghum, unlike other cereal grains, drastically loses its in vitro protein digestibility when cooked (Axtell et al. 1981, Axtell et al. 1982, Mertz et al. 1984). However, percent digestibility of fermented sheet-baked sorghum products (*kisra* and *abrey*) from the Sudan was found to be similar to or higher than that of the uncooked grain, indicating that fermentation improved digestibility (Axtell et al. 1982, Eggum et al. 1983).

Standardizing the Technology for Laboratory Use

Small quantities (60 g) of unprocessed grain from Uganda were processed using wood ash and 0.01 NaOH. Treatments and results are presented in Table 2. In all cases (except where the grains were soaked in water) processed grains changed color from brown to black, similar to the traditionally processed grain. The percentage of dry matter loss was low (3-4%) for treatments where the grains were not germinated, but higher (16-17%) for treatments where the grains were germinated. There was reduction in assayable tannins of up to 61% for the treatment where the untreated grains were soaked in water and an additional 11% when germination followed. However, the percentage of reduction of assayable tannins was very high (96-97%) when the grains were mixed with wood ash slurry, wood ash slurry filtrate, or residue. An additional small reduction (2-4%) resulted when these treatments were followed by germination. The percentage of reduction in assayable tannins caused by 0.01 NaOH did not differ significantly from the percentage of reduction following wood ash treatments. It appears from these studies that any amount of wood ash is effective in reducing assayable tannins without germinating the grain. Calcium and potassium were found to be the major chemical components in sample wood ashes from both Uganda and USA. The pH of both wood ashes was the same (11.5).

Applying Standardized Processing Technology to Different Grain Types

The effect of ash treatment on sorghum grains differing in color, testa layer (absent or present), tannin content, endosperm texture and type, seed size, and seed shape was determined by mixing 100 g grains of each cultivar with 15 mL wood ash slurry, soaking in water for 12 h, and drying at room temperature. Wood ash slurry was obtained dissolving 100 g wood ash in 100 mL water. The objective of processing these grains was to find out whether sorghum grains differing in physical and chemical grain characteristics behave differently when treated with wood ash.

Color changes after the wood-ash treatments varied among the 40 cultivars tested. Grains of only 13 cultivars changed from brown to black, as did grains of the local cultivar from Uganda. Grains of the other cultivars changed only slightly. Cultivars with grains that did not change from brown to black after processing were unacceptable. The tannin content of unprocessed grains of the 40 cultivars ranged from 0.00 to 15.31 catechin equivalent (CE) (methanol extracted) and from 0.00 to 1.65 CE (acidified methanol). We separated the 40 cultivars into four groups. The treatment with wood ash was effective in reducing tannin (methanol) in the high-tannin groups but not as effective for tannin extracted in acidified methanol. Because tannin content in the low-tannin groups was very low, treatment with wood ash made no significant difference (Table 3).

The effect of wood ash slurry concentrations on the tannin content of grains of six high-tannin cultivars was determined by mixing 100 g of each with 15 mL of six different concentrations of wood ash slurry and then soaking in water for 12-15 h. The six slurry concentrations were obtained by dissolving 100 g wood ash in 50, 100, 200, 300, 400, and 500 mL water. Grains of cultivars that did not receive the ash treatment did not change color after soaking in water. Grains of IS 12591, IS 21045, and IS 21003 changed grain color slightly with the lower wood ash slurry concentration treatments (400-500 mL), but became much darker with intermediate concentrations (200-300 mL), and turned black with the highest concentrations (50-100 mL). Grains of IS 9215 changed color slightly when treated with low and intermediate slurry concentrations (500 mL, 400 mL, 300 mL, 200 mL). At higher concentrations (50 mL, 100 mL), the grains of IS 9215 changed from brown to dark brown. Grains of IS 7177 changed from brown to black at even the lowest wood ash slurry concentration (500 mL) while grains of IS 8182 did not change color at low and intermediate slurry concentrations, but changed slightly at the highest concentrations.

Reduction in assayable tannins extracted in methanol was low and insignificant for all grains of the six cultivars when they were soaked only in water (with-

Table 3. Mean and range of tannin content (CE) of untreated and treated sorghum grains grouped on the basis of tannin content and tannin types.

		Untreated		Wood ash treatment plus soaking[1]	
Tannin classification		Methanol	Acidified methanol	Methanol	Acdified methanol
Low tannin Group I	Mean	0.01	0.05	0.02	0.02
	Range	0.00-0.2	0.00-0.10	0.00-0.06	0.01-0.03
Low tannin Group II	Mean	0.05	0.30	0.06	0.01
	Range	0.00-0.22	0.10-0.58	0.00-0.19	0.00-0.02
High tannin Group III	Mean	2.65	0.61	0.02	0.11
	Range	1.38-3.84	u.26-1.12	0.00-0.05	0.00-0.38
High tannin Group IV	Mean	7.37	0.98	0.06	0.16
	Range	5.19-15.31	0.55-1.65	0.00-0.47	0.00-0.77

SE untreated = ±0.031 methanol and ±0.010 acidified methanol
SE treated = ±0.003 methanol and ±0.112 acidified methanol

1. Grains (100 g) mixed with 15 mL of wood ash slurry (100 g dissolved in 100 mL of water and soaked in water for 12 h).

out the wood ash treatment). At the lowest wood ash slurry concentration (500 mL), tannin content (methanol) of grains of IS 9215 was reduced significantly from 5.40 to 0.01, while that of IS 7177 was reduced from 6.49 to 0.14. Grains of the remaining four cultivars required higher wood ash slurry concentration treatments to significantly reduce their tannin contents to below 0.2 CE. The grains of IS 8182 required the highest wood ash slurry concentration (100 mL) treatment to reduce their tannin content to below 0.1 CE (Fig. 1). Significant reduction in assayable tannin extracted in acidified methanol required higher wood ash slurry concentrations (Fig. 2). At 200 mL wood ash slurry concentration grains of IS 9215 were

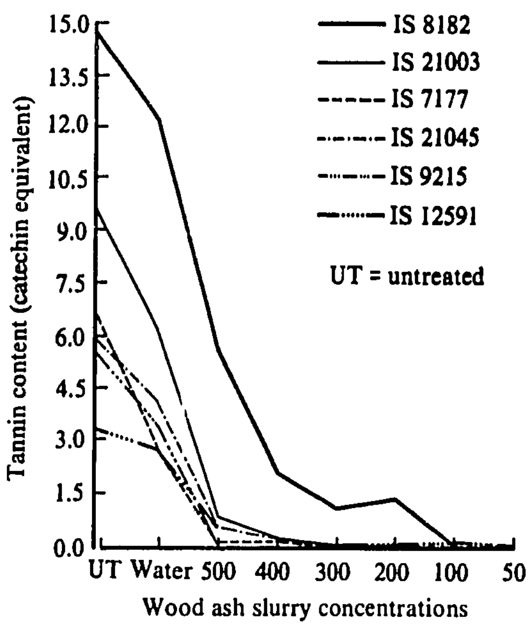

Figure 1. The effect of six wood ash slurry concentrations on tannin content (extracted in methanol) of grains of six high-tannin sorghums.

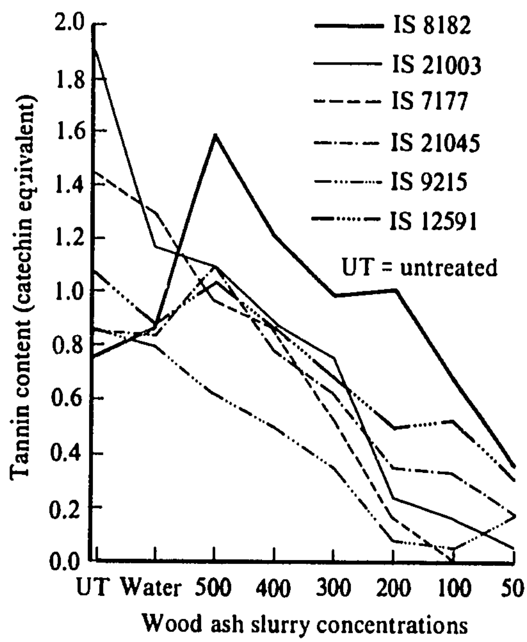

Figure 2. The effect of six wood ash slurry concentrations on tannin content (extracted in acidified methanol) of grains of six high-tannin sorghums.

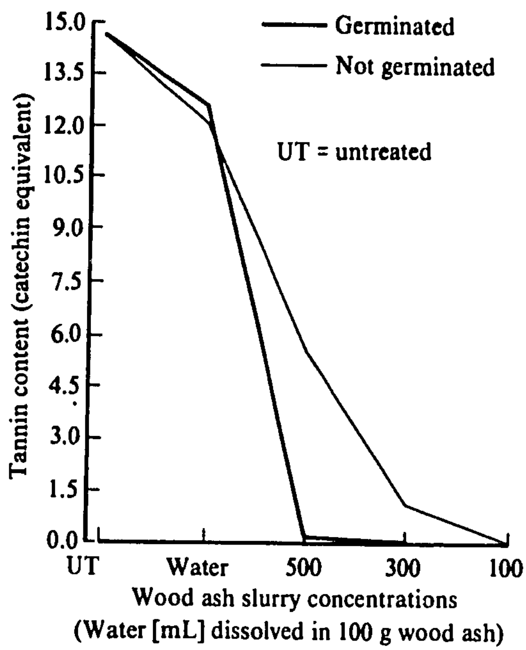

Figure 3. Tannin content (methanol) of IS 8182 grains treated with different concentrations of wood ash slurry and soaked in water for 12 h or soaked in water for 12 h and germinated.

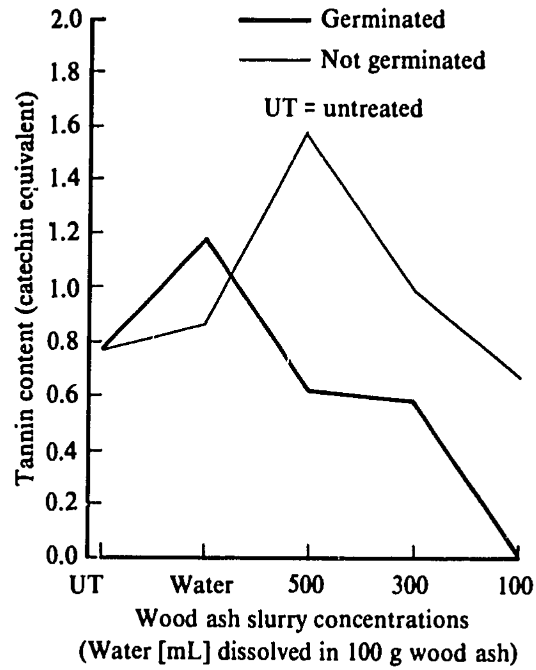

Figure 4. Tannin content (acidified methanol) of IS 8182 grains treated with different concentrations of wood ash slurry and soaked in water for 12 h or soaked in water for 12 h and germinated.

reduced to 0.08 CE and those of IS 7177 to 0.16 CE, while those of IS 21003 required 100 mL, and grains of IS 21045 required 50 mL wood ash slurry concentrations. Even at the highest concentration (50 mL) treatment, tannin content (acidified methanol) of the grains of IS 8182 could not be reduced to below 0.20 CE. However, a combination of the lowest wood ash slurry concentration (500 mL) and germination significantly reduced tannin content (methanol) of IS 8182 to below 0.2 (Fig. 3). Tannin content (acidified methanol) of grains of IS 8182 required a combination of higher wood ash slurry concentration (100 mL) and germination to reduce tannin content to below 0.1 CE (Fig. 4).

Experiments were also carried out to determine the length of time required to soak the high-tannin grains in water after wood ash treatment to reduce assayable tannins to acceptable levels. Grains of four cultivars (IS 8182, IS 21003, IS 7177, and IS 9215) were mixed with wood ash slurry and then soaked in water for 1, 3, 6, 9, 12, and 15 h (Fig. 5). Wood ash slurry was obtained by dissolving 100 g wood ash in 100 mL water. Grain of IS 7177 and IS 21003 changed from brown to dark brown only after 6 h of soaking and did not change subsequently. Grains of IS 8182, on the other hand, did not change color after 3 h of soaking. After 6 h of soaking, however, the grains

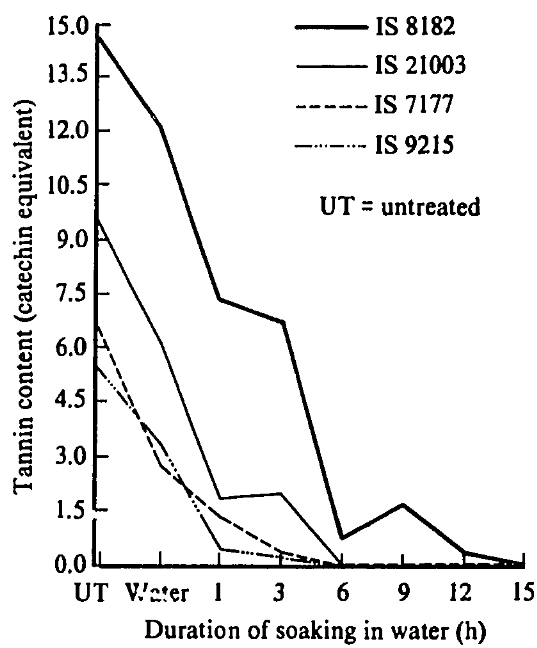

Figure 5. The effect of soaking grains of four high-tannin sorghums in water after wood ash treatment on tannin content (extracted in methanol).

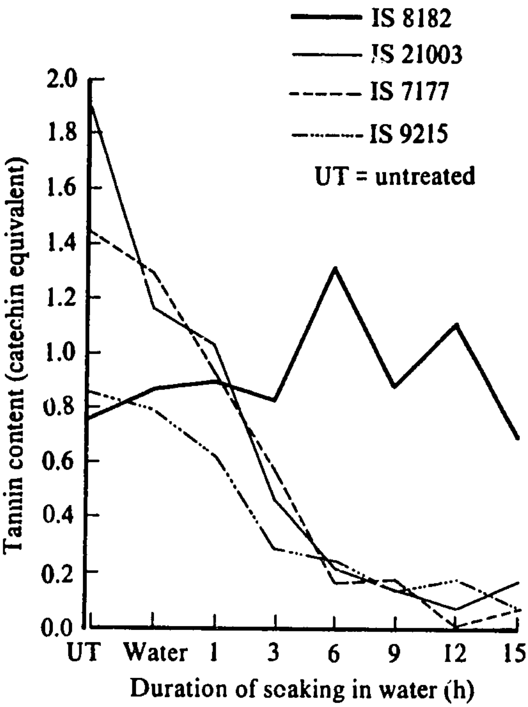

Figure 6. The effect of soaking grains of four high-tannin sorghums in water after wood ash treatment on tannin content (extracted in acidified methanol).

changed slightly from light brown to brown. Assayable tannin (methanol) of grains of IS 9215 was reduced from 5.40 to 0.43 CE after 1 h soaking, from 6.49 to 0.35 CE for IS 7177 after 3 h soaking, from 9.46 to 0.03 CE for IS 21003 after 6 h of soaking, and from 14.60 to 0.40 CE for IS 8182 after 12 h soaking (Fig. 6). After 9 h of soaking, assayable tannin (acidified methanol) for IS 9215 was reduced to 0.13 CE, for IS 21003 to 0.14 CE, and for IS 7177 to 0.17 CE. Grains of IS 8182 were only slightly reduced (from 0.76 to 0.69 CE) even after 15 h soaking. In fact, assayable tannin (acidified methanol) for grains of IS 8182 appeared to increase after 6 and 9 h of soaking.

Effect of Wood Ash-Treated Grains on Rat Growth

In 1986, rat feeding trials were conducted with the grains of two sorghum hybrids, BR 64 (high tannin) and RS 610 (low tannin) at Purdue to determine the effect of wood ash treatment on the growth of weaning rats.

Diets containing four treatments each of BR 64 and RS 610 were fed to weaning rats for 20 days.

Treatments and results are presented in Table 4. Wood ash Treatment 3 reduced assayable tannin content for BR 64 grains by 96%, and Treatment 4 by

Table 4. The effect of four different treatments on grains of two sorghum hybrids – RS 610 (low tannin) and BR 64 (high tannin) – on their protein and tannin content, in vitro protein digestibility, and rat weight gain after 20 days' feeding.

Sorghum variety	Treatments	Protein (%)	Tannin content (CE)	In vitro protein digestibility (uncooked)	Rat weight gain (g)
RS 610	1	8.8	0.00	84.2	45.5
	2	9.0	0.14	56.6	27.9
	3	8.9	0.07	81.2	36.5
	4	9.3	0.02	52.3	14.3
SR 64	1	8.0	10.04	13.3	7.2
	2	8.4	6.38	27.4	1.5
	3	8.3	0.39	75.4	52.5
	4	8.7	0.03	53.7	30.4
SE			±0.046	±0.53	±2.30

Treatments as follows:
1 = Control (untreated).
2 = Grains soaked in water for 12 h and germinated for 4 days at room temperature.
3 = Grains mixed with wood ash slurry and soaked in water for 12 h and germinated for 4 days at room temperature.
4 = Grains germinated for 4 days at room temperature.
CE = Catechin equivalent.

99%. Simultaneously, in vitro protein digestibility was increased by five times in Treatment 1 and by four times in Treatment 4. On the other hand, wood ash Treatment 3 for RS 610 decreased in vitro protein digestibility from 84.2% to 81.2%, while Treatment 4 decreased it from 84.2% to 52.3%. Soaking the grain in water and then germinating it increased in vitro protein digestibility of grains of BR 64 only slightly (from 13.3% to 27.4%), but decreased in vitro protein digestibility of grains of RS 610 (from 84.2% to 56.6%). Weaning rats fed BR 64 subjected to Treatment 3 gained 52.5 g after 20 days, significantly more than those fed diets containing treated and untreated grains of BR 64 or RS 610. Weaning rats fed diets containing BR 64 subjected to Treatment 2 gained significantly less weight than those fed diets containing untreated BR 64 (control). Weaning rats fed diets containing RS 610 subjected to Treatments 2, 3, and 4 gained less weight than those fed diets containing untreated RS 610. Grains of BR 64 and RS 610 developed mold during germination, partly explaining the poor performance of rats fed diets containing germinated grains.

Discussions and Conclusions

Effective traditional dehulling and grinding technologies for small grain developed by resource-poor farmers in the semi-arid tropics of Africa and India are still commonly used. These technologies utilize locally available equipment such as wooden mortars and pestles for dehulling and grinding stones. Traditional grain dehulling, which involves pounding damp grain in a mortar with a pestle, winnowing, and grinding dehulled grain, is a tedious and time-consuming job. In India, the dehulling process has generally been discarded and is only used occasionally. Increased urbanization and the availability of electrically powered flour mills have prompted consumers to use grit from whole grains (Mukuru et al. 1982). In many African countries, small-scale mechanical grinders have been introduced for maize and sorghum (Mitaru et al.). In Botswana, small versions of IDRC/PRL batch dehullers are now being operated successfully in several villages by Rural Industries Promotion of Botswana (Boling and Eisener 1982). In Nigeria, where diesel or electric grinders and mills are available, dried dehulled grain is dry milled (Mukuru 1986). However, for many people in rural areas in Africa where mechanical grinders are unavailable or expensive, traditional dehulling is still practised. Research and development in the 1990s should give top priority to developing simple but effective technologies for resource-poor farmers for threshing, cleaning, dehulling, and grinding their small grains.

The traditional processing technology for high-tannin grain detoxifies the grains and significantly improves its nutritional quality to the level of low-tannin sorghum grains.

Germinated sorghum grain contains appreciable amounts of cyanogenic glycoside, which yields hydrocyanic acid (HCN) through hydrolysis and is potentially poisonous (Panasink and Butler 1978). However, Dada and Dendy (1987) reported that the removal of shoots and roots on germinated grain lowered the HCN content by more than 90%, and boiling the slurry or steaming the paste eliminated the HCN completely. Since the traditional method of preparating *obushara* or *omuramba* involves boiling the slurry, the HCN should be completely eliminated.

Traditional processing technology could be modified and transferred to resource-poor farmers in areas where high-tannin sorghums are produced because of the severity of the bird (*quelea*) constraint.

Acknowledgments

The summary of results reported in this paper were obtained from studies conducted at Purdue University in 1986 by S.Z. Mukuru in collaboration with the following Purdue professors: J.D. Axtell, G. Ejeta, L.G. Butler, A.W. Kirleis, and J.C. Rogler.

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Discussion

J.E. Cecil: If you fed the animals sprouted sorghum without cooking it, how did you know how much of the lower weight gain was because of a different level of cyanide?

S. Z. Mukuru: It is true that the sprouted grains were fed to rats without cooking. It is possible cyanide may be responsible for lower weights. This requires further investigation.

J.D. Axtell: What proportion of the sorghum grain in your village in Uganda is used for fermented and unfermented porridges versus that used for traditional *ugali*? Also, how widespread is ash treatment and traditional sprouting processing used? Are they practiced anywhere other than southern Uganda?

S.Z. Mukuru: In the past about 50% of the grains were used untreated for traditional *ugali* and the other 50% traditionally processed and used for beverages. At present very little grain is used for *ugali*. Approximately 80% of the grain produced is traditionally processed and used for beverages. Traditional processing of high-tannin grain appears to be restricted to the southern highlands of Uganda and in neighboring areas in eastern Burundi and Rwanda, and probably Zaire. I do not know of any other area in East Africa where high-tannin grain is traditionally processed using wood ash. There are reports that high-tannin sorghum grain is treated with *magadi* soda in Tanzania.

J.N. Mushonga: Is there any color difference between treated and untreated sorghum?

S.Z. Mukuru: Yes. There are color differences in products from processed and unprocessed grains. Beverages made from unprocessed grains are brown while beverages made from processed grains are off-white with black specks. Unprocessed grains are not used to prepare alcoholic beverages.

J.M. Mwale: Did you measure the pH of the ash solution?

S.Z. Mukuru: Yes, it was 11.5.

O. Olatunji: Are there health hazards associated with the local method of processing sorghum?

S.Z. Mukuru: As far as I know no health hazards at all are associated with the local processing method. It has been reported that germinated grains contain high amounts of cyanide but subsequent studies have shown that traditional food preparation eliminates hydrocyanic acid (HCN) completely.

M.I. Gomez: Do you have any explanation of the difference in the pattern of protein digestibility between BR 64 and the low-tannin sorghum using the wood ash treatment?

S.Z. Mukuru: In vitro protein digestibility of RS 610 untreated grain and that of grains treated with wood ash and soaked in water are not significantly different. The low in vitro digestibility of germinated grains of RS 610 may be due to molds that develop on the grains during germination.

A.B. Obilana: D.A.V. Dendy of ODNRI reports that cyanide in germinated seeds or young seedling sprouts is removed by indigenous processing or use of ash is significant. This confirms the long-time use of such grains in weaning foods and lactating mothers' foods (thin porridge) in Africa. It nullifies the fear of health hazards associated with foods from such grains.

A.O. Koleoso: Did you determine the concentration of the alkali in the wood ash—possibly as potash?

S.Z. Mukuru: Wood ash from Uganda and West Lafayette, USA, were analyzed for their chemical components. Calcium was found to be the major mineral component, followed by potassium. A broad range of other elements including aluminum, iron, magnesium, phosphorus, sulfur, etc, were found to be present in lower concentrations.

J.M. Mwale: Would there be any difference in terms of type of equipment to use at village level compared to modern equipment?

S.Z. Mukuru: No, no difference at all. We have obtained similar results with various types of equipment in the laboratory.

Traditional Technologies in Small Grain Processing: Roasting and Malting—The Tanzanian Experience[1]

N.T.A. Bangu[2]

Abstract

A recent survey of sorghum utilization in Tanzania revealed that, in some localities, there exists a traditional practice of roasting sorghum prior to grinding into flour and subsequently using it to prepare soft and/or stiff porridges. People practicing the technique assert that it improves the flavor and other edible traits. The practice is, however, uncommon in the country. This paper discusses the potential of the technique as a means of enhancing acceptability of sorghum by a wider sector of the population. The paper goes on to examine research needs to strengthen the recently introduced "power flour" technique.

Introduction

The potential of sorghum as a food resource of strategic importance in the semi-arid tropics is well documented. However, cereals such as wheat, rice, and maize are usually preferred by consumers to sorghum. In view of this, considerable research effort is being directed towards sorghum utilization to achieve a better understanding of the constraints to increased utilization and to formulate strategies to overcome them.

In a recent survey on patterns of sorghum utilization in Tanzania, it became apparent that in certain localities in the Lake and Tabora regions, a traditional practice exists of roasting sorghum prior to grinding and preparing stiff porridges. The users of this practice assert that the roasting process facilitates processing (stone grinding) and improves eating quality. The practice, however, is not common throughout the country. The survey was therefore intended to determine the effect of roasting sorghum on milling characteristics and consumer acceptability in areas where such traditions did not exist.

Materials and Methods

Sorghum (variety *Mbangala*) was obtained from Morogoro, Tanzania. It was roasted over charcoal ovens in batches of 2 kg in frying pans. The roasting was conducted for different periods of time: 0, 5, 10, and 15 minutes. After cooling, each of the samples was ground into flour using a Magic Mill III® at the fineness setting level of 3 (the mill has a range of 1-6).

Particle size distribution

A portion of each sample was subjected to sequential sieving through sieves of sizes 810, 572, 500, 400, 315, and 210 μ fixed to a Podmore® vibrator. To enhance sieving efficiency a brush was used to dislodge clamping and sieve blockage.

Preparation of porridges

Stiff porridges were prepared by adding flour to boiling water (1 part flour to 2 parts water) and stirring

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5 min with a wooden spoon to make a thick cooked paste. Thin porridges were prepared with a 1:5 water:flour ratio.

Sensory evaluation

Sensory evaluation of the porridges was carried out at Melela village near Morogoro Township where sorghum is the staple food. Ten panelists were randomly selected. Each individual was served weighed portions (200 g) of each of the four samples with a meat sauce. The individuals were placed in such a manner that they could not see each other.

Sensory evaluation for thin porridges was carried out a week later using the same individuals as panelists. Each was served approximately 250 mL of each of the porridges. A little sugar was added to each porridge.

Determination of viscosity

Porridge viscosity was measured by adding 20 g of each flour sample to 200 mL cold tap water. The mixture was heated to boiling with intermittent stirring. The porridge was allowed to boil for 2 min and then cooled to room temperature. The viscosity was determined using a rotary viscometer (Model LV-8). A number 4 spindle and a speed of 12 rpm were used.

Results and Discussion

Particle size distribution

The particle size distribution is described in Table 1. It appears that in flours of the roasted samples there was a lower proportion of coarse particles compared with flours of unroasted grain. This observation is consistent with the assertion made in localities where roasting is practiced, thus substantiating the assertion that the technique of roasting makes grinding easier.

Sensory evaluation

The percentages of residue following a sampling of stiff and soft porridges in Melela village are shown in Table 2. The results indicate a preference for roasted porridges but not for stiff porridges. The panelists reported that stiff porridges made from roasted sorghum had an undesirable mouthfeel. In the case of stiff porridge from sorghum roasted for 15 min, the porridge was described as visually unattractive (it was chocolate brown) and somewhat bitter. The concentration of flour was lower in the soft porridge, which had a light brown color. On the whole, porridges made from roasted sorghum were accepted much more readily than those made from unroasted sorghum. They were described as smooth and flavorful, while unroasted sorghum porridges were described as lumpy and unattractive. The latter porridge had a dirty white color and set into a jelly only 10 minutes after it was removed from the heat.

Table 1. Particle size distribution in flour made from roasted sorghum.

	Flour retained after roasting for:		
Sieve size (μ)	0 min (450 g)	5 min (440 g)	15 min (400 g)
810	39.24	22.82	15.20
572	32.82	40.59	9.80
500	78.92	68.67	26.52
400	40.70	36.01	14.09
315	80.79	80.58	62.06
210	127.84	89.14	143.52
142	36.28	48.45	89.95
98	3.46	8.89	20.08
50	-	1.48	17.36
Total	446.05	396.63	398.58

Table 2. Percentage of pooled remains of stiff and soft porridges made from roasted sorghum.

	Roasting time (min)			
	0	5	10	15
Thick porridge remaining (%)	8	21	78	93
Thin porridge remaining (%)	90	27	36	18

Viscosity measurements

The viscosities of porridges made from sorghum roasted at different times are shown in Table 3. Roasting of sorghum significantly affected the viscosity of porridge. The porridge took well over 12 h to gel from the time it was removed from the heat. This feature contributed to the greater preference for porridge made from roasted sorghum. The fact that equal amounts of roasted and unroasted flour were used in the sensory evaluations suggests that larger amounts of flour could be used without rendering the porridge unduly stiff. This feature indicates the possibility of a second type of "power flour" for the weaning of children (the first type was described by Mosha [1986]). Although such a second type of "power flour" might have several advantages over the first type, the nutritional adequacy of such roasted flours requires evaluation.

Table 3. Viscosity of soft porridges made from roasted sorghum.

Roasting time (min)	Viscosity (centipoises)
0	7310
5	1170
10	950
15	710

Potential Methods for Improving the Nutritive Value of High-Tannin Sorghums in Tanzania

E.S. Monyo[1], M. Hassen[2], J.D. Axtell[2], and G. Ejeta[2]

Abstract

A unique mineral soil found in Tanzania has been found to possess certain properties advantageous for the cultivation of high-tannin sorghums. The soil, known locally as mmbala, *is rich sodium and potassium. Water extracted from* mmbala *has a pH of 9.7 and is used for preparing hard-to-cook legumes such as kidney beans and cowpeas. Experiments with high-tannin sorghum varieties indicate the soil's beneficial effect on nutrition.*

Introduction

Mmbala (also known as local *magadi* in Kilimanjaro, Tanzania) is a special mineral soil found in large quantities in the region. The name "local *magadi*" was coined due to an industrial product with similar properties, raw *magadi* soda. This product is a sodium sesquicarbonate salt (Na_2CO_3 $NaHCO_3$ H_2O) manufactured by the Magadi Soda Company in Kenya (Muindi et al. 1981). *Mmbala* is also very rich in sodium and potassium salts (11 625 ppm Na+ and 120 ppm K+) and evolves a considerable amount of CO_2 when treated with hydrochloric acid. Water extracted from this mineral soil has a pH of 9.7. It is used for preparing hard-to-cook legumes such as red kidney beans and cowpeas. It is also used in the preparation of whole grain maize and to treat hay before feeding to livestock. Food cooked with the water extract from local *magadi* cooks rapidly, eliminates heartburn, and forms less gas in the stomach. It is also believed to be better nutritionally. In some parts of southern Tanzania, a rice-like food product is prepared from pearly white, vitreous endosperm whole grain sorghum (Saadan 1983). This is similar to the whole grain maize food type prepared in the north but without the local *magadi* extract. Since beans contain some tannins, it is valuable to examine how the treatment affects the nutritive value of high tannin sorghums.

In this study, food was prepared from two sorghum varieties, P721N (tannin free) and IS 1291 (high tannin), with and without the local *magadi* extract, to investigate the effect of the extract on the in vitro protein digestibility of high- and low-tannin sorghums.

Materials and Methods

Preparation of the local *magadi* extract

The extract was prepared by dissolving 125 g local *magadi* L^{-1} of water. After mixing thoroughly, it was left to stand for about 24 h. The supernatant was filtered by passing through several layers of cheesecloth to trap any dirt, and the residue was discarded. The extract was used for cooking.

Cooking procedure

Two sorghum varieties, P721N (tannin free, crop year 1987) and IS 1291 (high tannin, crop year 1987) were each subjected to four different cooking treatments. A

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200 mg sample of seed from each variety was (1) cooked in 2 mL water; (2) cooked in 2 mL local *magadi* extract; (3) cooked in 2 mL sodium bicarbonate (1% solution); and (4) ground in a Udy Mill® (Boulder CO, USA), passed through a 0.4 mm screen, and cooked in 2 mL water for 20 min in boiling water. The seed samples subjected to Treatments 1 and 2 were also cooked in boiling water until tender (approximately 4 h).

The pepsin used in the treatments was porcine pepsin 1:10,000 (Sigma), activity 1200-2000 units mg^{-1} protein. In the pepsin method, the cooked samples were made into a slurry using a mortar and pestle, and the pH was adjusted to between 6 and 7 with HCl before treatment with pepsin (pepsin is inhibited under strong alkali conditions). The modified pepsin method of Mertz et al. (1984) was used. The samples were suspended in 35 mL of the pepsin solution (1.5 g enzyme L^{-1} 0.1 M phosphate buffer [KH_2PO_4], pH 2.0). The mixture was incubated in a 37°C water bath for 2 h. Pepsin digestion was stopped by addition of 2 mL 2 *M* NaOH. The suspension was centrifuged (12 000 × g for 15 min at 4°C) and the supernatant discarded. The residue was resuspended in 10 mL 0.1 *M* phosphate buffer (pH 7.0) and centrifuged as before. The supernatant was again discarded and the residue dumped onto a Whatman filter paper no. 3, through a 43-mm Büchner funnel. Suction was applied and the residue was washed into the funnel with 5 mL of the phosphate buffer pH 7.0. The residue was rolled into the filter paper and inserted in a Technicon digestion tube. The temperature in the sulfuric acid digestion process was started at 100°C and raised in increments to 350°C over a span of 2.0. To remove carbonatious materials during the digestion, H_2O_2 was used three times. After the solution was completely clear, the remaining nitrogen in the form of ammonia was determined by the Technicon analyzer. Digestibility was calculated by subtracting residue nitrogen from total nitrogen, dividing by total nitrogen and multiplying by 100.

Results and Discussion

Even without tannin, the protein digestibility of cooked sorghum is lower than that of other major cereals (Hamaker et al. 1987, MacLean et al. 1981, Mertz et al. 1984). This decrease in digestibility is thought to be caused by formation of disulfide bonds during cooking, thereby creating less digestible proteins (Hamaker et al. 1987). The tannin contents of the two varieties and their effects on pepsin digestibility are shown in Table 1. Variety IS 1291, with high tannin, had the lowest protein digestibility (27.5%), compared with 52.5% for tannin-free P721N when cooked as a gruel in water for 20 min.

Cooking sorghum seeds until tender (approximately 4 h) slightly improved the in vitro pepsin digestibility of the high-tannin sorghum, compared to merely cooking the flour in water for 20 min (32.0% vs 27.5%). However, the pepsin digestibility of the tannin-free variety was reduced (41.5% vs 52.2%), probably due to more disulfide bond linkages caused by the extra cooking time. When sorghum seeds were cooked in local *magadi*, the pepsin digestibility of the high-tannin variety was improved to the level of the tannin-free variety. This implies that the *magadi* treatment neutralized the anti-nutritional effects of the tannin and improved the nutritional value of the high-tannin variety. Improvement of the nutritive value of high-tannin sorghums by the use of industrial *magadi* has also been reported by Muindi et al. (1981b).

Treatment with a 1% sodium bicarbonate solution had the same effect on the high-tannin sorghum variety as the local *magadi*. In areas where the local *magadi* is unavailable, sodium bicarbonate or industrial *magadi* are therefore viable alternatives for detoxification of high-tannin sorghums.

Table 1. Effect of preparation methods on the in vitro protein digestibility of high- and low-tannin sorghums.

Variety	Tannin (CE g methanol^{-1})	Treatment	Pepsin digestibility
P721N	0.0	Flour cooked in H_2O (20 min)	52.5 ± 0.7
IS 1291	7.1	Flour cooked in H_2O (20 min)	27.5 ± 0.7
P721N	0.0	Seeds cooked in H_2O (4 h)	41.5 ± 2.1
IS 1291	7.1	Seeds cooked in H_2O (4 h)	32.0 ± 1.4
P721N	0.0	Seeds cooked in magadi (4 h)	51.9 ± 3.3
IS 1291	7.1	Seeds cooked in magadi (4 h)	48.9 ± 3.3
P721N	0.0	Seeds cooked in $NaHCO_3$ (4 h)	58.0 ± 1.4
IS 1291	7.1	Seeds cooked in $NaHCO_3$ (4 h)	44.5 ± 0.7

CE = Catechin equivalent.
Source: Price et al. 1978.

Local, inexpensive methods exist in Africa for overcoming the harmful effects of tannins. Food types such as *nasha* (Sudan) and *kisra* (Ethiopia), which have nutritive value far superior to that of sorghum gruel, in addition to methods such as *magadi* treatment, are examples of the potential. Due to serious problem of *quelea* birds throughout eastern Africa, high-tannin sorghums will continue to be imported to that region. The need for development of new methods to help in the utilization of high-tannin sorghums is thus essential.

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Secondary Food Processing

Composite Flour—Past, Present, and Future: A Review with Special Emphasis on the Place of Composite Flour in the Semi-Arid Zones

D.A.V. Dendy[1]

Abstract

The use of blends of wheat and nonwheat flours, known as composite flour, became prevalent when wheat was scarce. Since the 1960s, much research aimed at incorporating nonwheat material of local origin on bread and other flour products was undertaken, thus limiting wheat imports. Because the Government of Nigeria has banned wheat imports, this technology is no longer relevant. Opportunities exist for composite flour where wheat is available locally or can be imported without undue economic constraints, and where local cereal flours can be blended into wheat flour for breadmaking. The technology is available, and composite flour programs should be part of national policies on sorghum and millets. Opportunities also exist for blending indigenous cereals into products from exotic grains such as maize.

Introduction: The Bread Economy

Many countries in the Third World have become heavily dependent on staple foods which they import and for which conditions for local production are poor or nonexistent. Once established, such a dependent consumption pattern is self-reinforcing (Andrae and Bechman 1985).

One could add that both the food and the food habit are imported. Not only improved grains such as wheat should be considered, but nonindigenous grain crops such as maize which were imported earlier and are now established, although they are less suited to harsh climates than indigenous sorghum and pearl millet.

To understand the importance of composite flour in developing countries, one must first understand how the bread habit was acquired.

The essential ingredient of bread is wheat—more particularly, the unique wheat protein known as gluten. Wheat originated in the Vavilov Center between the Caspian Sea, the Black Sea, and the Mediterranean. In Roman times wheat was traded in Britain and elsewhere, but it was not until the nineteenth century that wheat and flour were traded to places where wheat had not previously been grown: tropical regions colonized by the European powers. Freed slaves from Brazil undoubtedly also played a part in the establishment of the bread habit in parts of West Africa during this period.

The bread habit, derived in part from the convenience and wholesomeness of bread, was sustained by vigorous advertising of bread as a convenient and upmarket food. Unfortunately, bread must be purchased with hard currency. Countries with wheat surplus are anxious to establish and maintain markets, particularly in the face of declining markets in Europe and North America. In most developing countries there are flour mills, many of them recently built, to process this wheat and thus sustain the bread habit. Fur-

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thermore, when famines occur, wheat is often donated or sold below production cost to ameliorate the deficit of local staple foods. In Bangladesh, for example, after wheat was donated during the famines of the early 1970s, a massive effort to grow wheat as a second (winter) crop was undertaken to satisfy the wheat-eating habit (mainly as chappatis rather than bread). Previously, wheat production in Bangladesh had been less than 1% of total cereal production: it is now over 5%.

In developing countries, a simple correlation exists between the increase in urban population and the increase in wheat imports (Edmunds 1970)—each is about 10% per annum.

The habit of eating bread also spread as a result of improvements in the transport infrastructure. Possibly, the best documented case study is that of Nigeria (Andrae and Bechman 1985). In 1965 Kilby wrote a book on Nigeria's locally owned bakeries. At that time wheat and flour imports totaled only 56 000 t—0.4% of the total carbohydrate-based diet (cereals plus root crops, expressed as 20% harvest weight). With new oil revenues enabling large purchases of wheat and investment in mills and bakeries, imports increased very rapidly, from 0.41 million t in 1975 to 1.67 million t in 1984—a total of 13.3% of Nigeria's cereal plus root-crop diet. Meanwhile, wheat production increased from 15 000 t in 1965 to 45 000 t in 1985, still only 2.7% of wheat consumption. It should also be noted that the cost in foreign exchange of this local production was extremely high, as wheat can only be grown with irrigation in the cool dry season. Andrae and Bechman (1985) concluded that the economic justification for wheat production in Nigeria was fraudulent. The illusions of the millers and wheat traders were shattered in January 1987 when the ban on wheat imports came into effect. With a single stroke Nigeria stood to save up to US$ 500 million per annum.

It is ironic that although the Nigerian Federal Institute for Industrial Research at Oshodi has worked on composite flour for many years, (i) no industrial uptake and little interest was shown by millers or bakers, (ii) no Government policy was developed, and (iii) the will to implement composite flour technology was lacking.

Composite Flours: History and Concept

This papers deals with the subject of composite flours, which may be considered as either:

a. a combination of wheat and nonwheat flours for the production of leavened breads, other baked products, and pastas; or
b. a wholly nonwheat flour prepared from mixtures of flours from cereals, roots, tubers, legumes, or other raw materials, to be used for traditional, western, or novel products.

Because the latter definition is too general to be of practical use, composite flour is usually thought of in terms of (a).

Nigeria is an extreme example of the bread habit corrupting an economy: only developing countries with vast mineral or oil wealth can afford such a massive change in diet, with the ensuing problem of sustaining an imported food habit after the wealth has gone. The situation in Nigeria therefore provided a prima facie case for the use of composite flours. The desirability of diluting wheat flour with locally available cereals and root crops (with the possible addition of a protein supplement) was clear. If successful, this development will encourage the local agricultural sector and lessen wheat imports at the same time.

Making bread by substituting part of the wheat is not a new idea. In ancient times, the most frequently used diluent was barley, and often bread containing large amounts of barley was the staple food of the poor. In Britain, barley, rye, oats, and sometimes beans were added to wheat flour, which in most years was too dear for the common people. Bran was frequently added to whole wheat flour for the poor to satisfy the demand for white flour of the wealthy (Drummond and Wilbraham 1957). By the end of the nineteenth century, Britain was importing large quantities of wheat from North America, domestic supplies having become too small for its large industrial population. When scarcity resulted during the First World War, imports were reduced. As in previous times of scarcity, it became necessary to add nonwheat materials to bread. Barley, which grows well in Britain, was chosen as the principal diluent. At first only 5% of the diluent was added to the wheat, but the quantity was gradually increased and by the end of the war, bread frequently contained about 20% "adulterant" and the wheat flour itself was at or above the 90% extraction rate. The emotive term "adulteration" is still used by millers and bakers who oppose composite flour programs. During the Second World War these mixtures were again used and today, during times of temporary scarcity of imported wheat, local materials have been used as diluents in developing countries. It was not, however, until the 1960s that scientific interest in composite flours was aroused.

T·· interest came about for two reasons: firstly, recent discoveries in starch chemistry and baking technology made possible the use of composites and even of gluten-free products for baking; secondly, there was an upsurge in interest in the food problems of the newly emerging nations of the tropics.

Composite flour technology owed much of its initial impetus to Pierre Chatelanat and the FAO. Chatelanat noted that wheat flour was expensive in Papua New Guinea and persuaded FAO to request a preliminary study at Wageningen, the Netherlands, initially on the use of cassava in bread. Three international organizations were active in the early days of composite flour research: the Tropical Products Institute (TPI, now the Natural Resources Institute [NRI], UK), Kansas State University (USA), and the Institute for Cereals, Flour and Bread (TNO), Wageningen.

It was the latter institute which made the fundamental scientific discovery that awakened interest in the possibilities of composite flour. TNO researchers noted that dough (and therefore bread) structures could be formed using starch with surfactants such as glycerol monostearate (GMS). It was found that the crumb structure and volume of bread improved by adding these surfactants and that weaker wheats could be used while retaining conventional crumb structure and volume. The Wageningen work was subsequently transferred to Colombia, where bread containing 30% cassava starch was baked at the pilot scale. Work on wheatless bread, however, was less successful.

The Flour Milling and Bakery Research Association at Chorleywood, UK, developed a process in the early 1960s whereby flour with lower than normal gluten content could be used to make bread by mechanical dough development.

Hulse et al. (1969) wrote a brief report entitled "Mechanically Developed Doughs from Composite Flours" using the Chorleywood process to produce bread containing 30% nonwheat material. The work carried out at TPI followed from this work, and the Institute has since (as NRI) been involved in composite flour since 1969 (Dendy et al. 1970, Crabtree and James 1982).

Other teams began work shortly afterwards, and in 1972, when the first Composite Flour Bibliography was published by TPI, it included 160 citations. In spite of the vast amount of scientific and technical research, however, little had been published on the economics of composite flour. There was also very little published concerning actual implementation. Few technologies have been so thoroughly researched and so little applied.

One reason for this abundant research but lack of literature was that, to many research workers, composite flour was an ideal subject for academic research. It was easy to attract funding and to convince authorities that the subject was worthwhile. Students were able to carry out the research with minimal resources, frequently only basic kitchen equipment. Papers sometimes concentrated on organoleptic studies, comparing composite flour bread with the all-wheat product and demonstrating its acceptability in terms of flavor. Although actual consumer trials were rare, they were successful in Colombia, Kenya, Nigeria, Sri Lanka, and Sudan. Where laboratories were well-equipped, often with external resources, the quality of composite flour bread was much higher than that of local bakers working with crude equipment, lack of process control, and infested flour.

Because scientific journals are favorably disposed to publishing papers on composite flour, the illusion of original research is easy to maintain. By the time the Second Supplement to the Second Edition of the TPI Composite Flour Bibliography appeared in 1979, an impressive total of 952 papers had been published. There was still, however, little or no implementation.

Composite Flours: Current Position

Most of the composite flour research was carried out on cassava, a little on sorghum, and very little on millets. Table 1 summarizes some of the work over the past 20 years and gives some idea of the levels of nonwheat addition that can be expected and targetted.

With proper preparation, up to 30% sorghum or any one of the four most common millets (pearl, proso, foxtail, finger) can be used, either by preparing the flours first or by co-milling—a technique described by Crabtree and Dendy (1979). For preparing the raw materials from sorghum, pearl millet, and maize, one can use new technologies (such as the PRL or the Decomatic dehuller), conventional roller mills, or the semiwet milling technique developed at NRI (Cecil 1986). This latter technique is particularly appropriate in countries with a surplus of roller-milling capacity. Unfortunately, this capacity for milling sorghum, maize, or pearl millet is rarely embraced with enthusiasm: most of the mills are controlled by wheat traders and others with negative views on composite flour. When preparing a composite flour program it is therefore important that millers, bakers,

Table 1. Suggested levels for nonwheat moieties (as percentage of total flour) for composite flour bread (wheat flours were of various strengths).

			Millets			
	Sorghum	Maize	Pearl	Proso	Foxtail	Finger
TPI (NRI)	15-30	10-20	10-20	10-20	10-20	10-20
FRC Sudan	20-30	-	-	-	-	-
KSU	10	-	-	-	-	-
KIRDI	15-20	10-15	-	-	-	-
CFTRI	20	20	-	-	-	-
ITA	15-30	15	-	-	-	-
ECA compendium	15-20	20-25	15-20	-	-	-
Suggested maximum	30	25	30	20	20	20

Table 2. Wheat usage (1981-83) and possible savings by adoption of composite flour.[1]

	Kenya	Sudan	Tanzania	Zambia	Zimbabwe
Imports of wheat	150	230	35	140	100
Production of wheat	240	140	70	20	120
Total	**390**	**370**	**105**	**160**	**220**
Costing (at US$180 t^{-1})[2] delivered	27 m	41 m	6 m	25 m	18 m
Flour at 80% extraction	312	296	84	128	176
Non-wheat cereal flour (80% extraction) needed for 25% CF bread	104	99	28	43	59
Cereal	130	124	35	54	74
Possible foreign exchange savings (at US$180 t^{-1})	23 m	22 m	6 m	10 m	13 m
Trade deficit	304 m[3]	135 m[4]	350 m[5]	-	-
Sorghum production	180	1819	460	9	58
Millet production	80	314	335	13	100
Maize production	2178	50	1363	900	1023

1. Figures represent thousands of tonnes.
2. This figure fluctuates daily with the dollar, the wheat price, and the transport cost.
3. 1984.
4. 1985.
5. 1981.

and consumer organizations be brought into the discussions with Government at an early stage, since Government support is the first prerequisite.

The basic criteria for the raw materials are:

1. wheat flour of reasonable strength—preferably over 12% protein (N × 5.7); and
2. clean, fine flour from the nonwheat cereal free from specks of colored bran, compatible in color with wheat flour, and of as low a fiber content as possible.

Note that if it is necessary to add fungal amylase or diastatic malt to the flour to offset a high falling number (in Zimbabwe, for example), then sprouted sorghum or other cereal can be substituted as a locally available source of diastase.

Table 2 gives the tonnage of nonwheat cereal required for composite flour programs using a hypothetical 25% of nonwheat flours as the ultimate goal. Acceptable bread can be baked at this level, but if a higher proportion of nonwheat flour is used one can still bake bread (though not of a quality similar to all-wheat bread). The loaf volume would be lower, the crumb less open and more cake-like, and the color darker.

Composite Flours: Decision-Making Criteria

Kenya, Sudan, Tanzania, and Zimbabwe grow wheat, but they also import it to satisfy the difference between production and consumption. These countries also grow sorghum, pearl millet, and maize. The savings in foreign exchange are considerable. In addition, local agriculture is boosted by providing markets for the large quantities of nonwheat cereals needed. Even when there is no foreign exchange deficit, the foreign exchange currently spent on wheat could be cut and the money put to better use.

Within the wider definition of composite flour, the opportunities are vast. Blends of maize and sorghum meals can make excellent *ugali (sadza)*, provided the varieties used have similar cooking characteristics. Two incompatible varieties of maize can produce an indigestible and therefore unacceptable product, so it is the type of endosperm rather than the species which is important. Wheatless bread substitutes could also be made.

Crabtree and James (1982) published a paper outlining TPI's experience in composite flour and suggesting 10 requirements for implementation of the composite flour program.

> TPI considers that the use of composite flour in breadmaking offers scope for beneficial developments in many tropical countries but experience to date has been discouraging, largely because of the *lack of infrastructure* in the formulation of composite flour programmes. The Composite Flour technology has long since been proven.

The following steps are necessary to set up a program.

1. A technical study should be undertaken to determine the level of nonwheat substitution that may be achieved under local conditions. Because much knowledge is already in hand, this study need only take *weeks*, not months.
2. An economic study is essential to evaluate the balance between the savings on wheat imports and the investment needed for the purchase of processing and blending equipment if these are not available.
3. A definite decision must be taken by Government to proceed wi h a national implementation program followed by a formulation of policy.
4. Availability of appropriate varieties of the diluent grain must be assured to provide optimal quality characteristics for the composite flour products.
5. Seed multiplication and seed supply capacity must be assured.
6. A program of increased production of the nonwheat diluent and the provision of incentives to encourage farmers to grow the commodity are of paramount importance.
7. The selection and installation of processing and blending equipment should be undertaken with due regard for the necessary cooperation of the millers.
8. The training of bakers in the use of composite flour in breadmaking is recommended. This may not be necessary, but the bakers must be involved in discussions from the inception of the program.
9. A market survey on the acceptability of the composite flour bread and the education of the consumer are of key importance. Consumer organizations and the press must be won over early in the program.
10. The formulation of quality standards for the grain and for the composite flour must be defined.

A further effort in public awareness of composite flour was made in 1985 by the UN Economic Commission for Africa (ECA) in the "Technical Compendium on Composite Flours" (1985). This book describes the technologies available for application: some of which have been available since the early 1970s. Technologies for preparation of raw materials, which TPI recognized in the early 1970s as crucial, are given due prominence, as are sorghum and the millets.

Composite flour should not be considered a stop gap to be used only when a foreign exchange crisis arise. It should be built into national grain policies, provided bread consumption can be limited to those markets requiring a convenience food. Parallel to this but potentially of much greater importance to national agriculture is the development of markets for new and improved products from sorghum and millets—products with the convenience of bread combined with the appeal of tradition. New products created from old grains must be given greater emphasis.

Sorghum and pearl millet are the true staples of semi-arid Africa. Some countries already have established sorghum and millet working groups and a few have policies to encourage the cultivation of these crops. These policies should not only be designed to promote new and traditional foods based solely on sorghum and millets, but should, as long as wheat is available, have a place in a composite flour program. After all, composite flour technology is already available. In order to facilitate its successful implementation, the paramount requisite is political will. It is our duty to make sure that governments realize that the technologies for composite flour and for sorghum and millet utilization are available. Governments must implement composite flour programs and small grain utilization as part of their national food security strategies.

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Discussion

L.R. House: Should we not attempt to identify traits in sorghum and millets for which breeders could apply a selection pressure that would lead to a better flour for blending into wheat?

D.A.V. Dendy: Yes, but varieties are available now which can be milled into white flours of suitable qualities for inclusion in composite flour bread, as for example the cultivar Dobbs.

A.V. Obilana: Dr House's comment on specific varieties and specific traits is significant. At IAR, Samaru, Nigeria, we found specific differences in breads baked using sorghums with white or yellow endosperm and red sorghums mixed with locally grown wheat. These differences also showed up in the different sorghum:wheat ratios of composite flour. It is important to remember, however, that the development of policies geared towards backing such, local uses of sorghum and millets in baking nonwheat and wheat composite breads is still up to the Government.

R.E. Schaffert: Has any work been done on the variation between food-type sorghum cultivars regarding industrial processing such as mixing time? Our work has indicated that there is a difference.

D.A.V. Dendy and **J. Faure**: Different sorghum cultivars have different potentials for incorporation into composite flour. Milling quality, i.e, the ability of the grain to yield a fine white flour free from bran, is very important. Cultivars with vitreous endosperm may well give a clearer separation of bran from endosperm.

A. Carney: Has the scale of technology and replication on industrial scale been tested? Have we checked the composite flour usage in commercial-scale bakeries as well as mills, and have we replicated baking trials that show consistent results?

D.A.V. Dendy: Yes. Commercial-scale production was carried out in Colombia, Senegal, Sri Lanka, and Sudan. In the 1969/70 season, ODNRI worked with a commercial bakery in the UK to prove that the composite flour doughs were machinable. Laboratory studies should use Farinograph as well as test baking to give advice concerning mechanical problems that might arise.

A.C. Moshe: How do we win over the politicians and sell them the idea of composite flour?

D.A.V. Dendy: I do not know. We all should explore this. Economic analyses and presentation of facts to influence policy will help to counter the lobbying by opposing bakers.

O. Koleoso: The way to convince millers to use composite flour commercially is through economic squeeze, like in Nigeria. Also, the use of cassava in composite flour has been carried out in Nigeria and a substitution of 20% is adequate.

R. Jambunathan: You have shown 80.1% extraction rates for wheat and nonwheat cereals. Is this practically feasible?

D.A.V. Dendy: Yes. For wheat one can mill at anything from 60% to 100%. For sorghum, some varieties give rather low rates (e.g., broomcorn sorghum – see the 1977 Dada/Dendy report), but for white and yellow cultivars and for red cultivars like Dobbs, 80% should be attainable on a commercial mill, since we can get 70% in our Bühler 202 lab mill.

J.M. Mwale: Probably one way of getting political will is to ensure that we get more scientists into political positions. Our experience has been that once we have a minister who has some scientific background, we do not need too much persuasion to get economic backing. A corollary should be that we try to ensure good reporting from journalists on scientific information; otherwise the reporting on scientific matters is usually carried out from a political rather than a scientific point of view.

Sorghum and Maize Pasta and Extruded Products

J.C. Faure[1]

Abstract

Although the technological problems of the partial or total replacement of wheat by sorghum or maize flour in baked products has been overcome, commercial success has been limited. Much less work has been done on composite pasta and noodles. A review of published results indicates that, without any additive, 30% sorghum is the maximum incorporation than can retain satisfactory cooking quality and color. Pregelatinization of 25% of sorghum flour, before blending it with the remaining 75%, gave good cooking characteristics, but the color was unacceptable to the consumers. An interesting alternative is the use of heat treatment during drying. This treatment proved successful when applied to spaghetti and noodles made from a blend of maize and wheat. At a ratio of 70:30 (maize flour:wheat semolina), cooking quality was found equivalent to 100% wheat products. In addition to appropriate heat treatment, the choice of flour (rather than semolina), a lipid content around 1%, and low ash content required to obtain acceptable pasta products for a given rate of incorporation.

Introduction

In 1980, a worldwide study was carried out by FAO on composite flour programs. The study indicated that bread was by far the commodity most studied. Biscuits and pasta were subject to less intensive research in both developed and developing countries (Table 1). Of 58 research centers in developing countries, mostly in Africa, 17 were studying partial or total substitution of wheat by sorghum or millets in cereal-based products (Table 2). In 1986, a survey on pasta products was undertaken by the Institut de recherches agronomiques tropicales et des cultures vivrières (IRAT) confirmed this situation (Table 3). Sorghum pasta attracted limited interest outside Africa and India, the main sorghum-producing areas.

Composite flour pasta in developing countries has little impact on the economy, since pasta consumption is very low compared with bread consumption (Abecassis et al. 1978). If successful, a composite flour bread marketed on a national scale would render thousands of tonnes of wheat imports unnecessary. Imports plus local production of pasta presently range from only 200–5000 t per year in most African countries where sorghum and maize are produced and could be used in composite flour (Centre français du commerce extérieur 1980). Local sources of pasta should be easy to organize at stable prices. Also, there are few mills and pasta plants in each country. If sorghum or maize pasta is found acceptable by consumers at reasonable prices, its popularity will expand gradually since it will be considered a new product rather than a substitute of low social standard. The situation is different for bread due to its already well-developed market and status. A change in bread crumb, structure, or color, which may result from the incorporation of more than 5-7% nongluten flour, will be immediately detected and probably rejected by consumers.

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Table 1. Composite flour programs.

	Bread	Biscuits	Pasta
Developing countries	50	30	18
Africa	9	4	-
South and Central America	26	19	12
Asia	11	6	6
Others	4	1	-
Developed countries	22	6	3
Total	72	36	21

Source: FAO survey on composite flour 1980.

Table 2. Research programs on nonwheat grains.

	Developed countries	Developing countries
Rice	5	14
Maize	4	12
Sorghum/millet	7	17
Quinoa	-	7
Barley/triticale	10	13
Total research centers	23	58

Source: FAO survey on composite flour 1980.

Quality and production of composite flour pasta are highly related to the characteristics of the flour used, and also to processing, particularly the drying stage.

Characteristics of Grains and Flour

The quality of pasta is highly related to the quality of raw material and also depends on the milling process. In addition to satisfactory agronomic characteristics, the following qualities are required from sorghum grains in order to provide an acceptable industrial flour for the pasta industry (Miche et al. 1977).

- ***Pericarp.*** The pericarp should be thin, translucent, light in color, and should not be friable for processing in roller mills. It can also be resistant, soft, and elastic for dehulling prior to grinding.
- ***Testa.*** No testa or anthocyanin are present in precursors or other phenolic compounds. Pasta color is directly related to the intrinsic color of sorghum variety due to the flavonols and tannins. Mainly located in bran, polyphenols are still found in sorghum semolina at a much higher rate than in durum semolina with 0.84 optical density against 0.16 optical density at 320 nm absorbance (Miche et al. 1977) and are responsible for brownness of pasta products.
- ***Endosperm.*** This has a floury, yellow color due to carotenoid pigments responsible for the yellow index of pasta, although these pigments are only half as numerous as those found in durum wheat: 0.10 optical density against 0.17 optical density at 400 nm (Miche et al. 1977).

The Milling Process

Milling yields are generally around 73% for sorghum varieties. The ratio of semolina to flour varies considerably. A lower extraction rate may significantly improve the pasta appearance. Milling fractions of less than 1% ash content and 1% lipid content are preferred for pasta and may be obtained by preliminary dehulling with a sorghum mill (Perten 1977) (Fig. 1) or by roller mills on a modified durum wheat diagram (Abecassis et al. 1978) (Fig 2). Milling fractions behave differently and directly influence pasta structure, appearance, and cooking quality. The surface of pasta is irregular and somewhat darker when purified sorghum semolina of 300 μ is used than with sorghum flour of 140 μ. Regrinding of semolina to reduce medium particle size improves cooking quality of pasta (Miche 1978). This is also observed with maize.

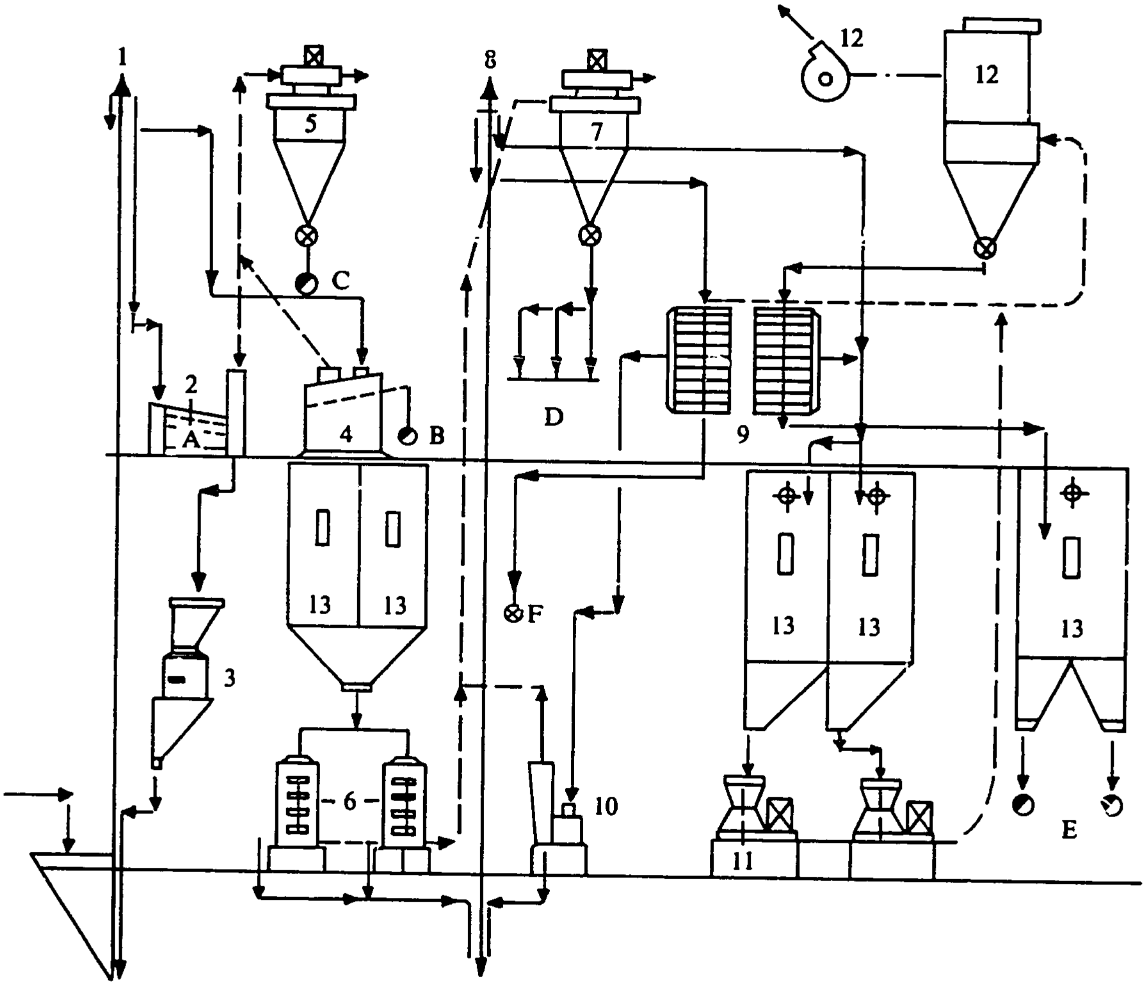
Semolina comes from the peripheral and vitreous endosperm which is hard and resistant to water penetration. Its starch granules are smaller and the protein matrix is more continuous than in the floury cells of the endosperm (Rooney and Sullins 1973, Rooney and Miller 1982). The hydration rate is therefore lower and should be balanced by a longer mixing time or by a further reduction in particle size. The protein denaturation in the continuous matrix during drying may also improve the cooking quality of pasta by reducing cooking losses in boiling water.

The increase of damaged starch in sorghum semolina by appropriate regrinding and more intensive shearing during mixing and extrusion improve hydration, thus eliminating white spots on the surface of pasta and giving cohesiveness to the pasta. Losses during cooking, however, are not reduced.

Table 3. Tentative list of composite flour pasta projects, 1972-86.

Formula	%	Country	Technical assistance	Scale	Comments	Reference/ year of study
Rice Wheat[1]	70 30	Colombia	TNO	Industrial		Salazar 1982 Navarro 1986
Millet Wheat	20 80	USA	Colorado State Univ.	Industrial	±4% sugar and 3% shortening used, noncommercialized	Lorenz 1983
Millet/ sorghum/ niebe Wheat	50 50	Nigeria (Maiduguri)	CRDI, Canada	Semi-industrial	Local noodle type (*talya*)	CRDI
Millet	100	Niger (SOTRAMIL)	FAO	Industrial	Poor cooking quality	FAO 1972-74
Millet Wheat	70 30	Niger	FAO	Industrial	Poor cooking quality	SCET-AGRI 1982
Sorghum Wheat	NS[2]	Mali (SOMOBIPAL)	NA[3]	Medium scale		SCET-AGRI 1982
Sorghum Wheat	30 70	France	IRAT, France	Industrial	Good cooking quality	Miche 1978
Sorghum	100	France	France	Industrial	25% pregelatinized, grayish color	Miche 1978
Maize Wheat	30 60	Colombia	-	Industrial	Precooked maize flour	Navarro 1976
Maize Wheat	30 60	France	IRAT/IRA, France	Industrial	Heat treatment, good quality	CIRAD/IRAT 1986
Maize Wheat	40 60	Central America	INCAP	Industrial	Good quality	Molina 1982
Maize Wheat Soya	32 60 8	Central America	INCAP	Industrial	Good quality	Fellers 1983
Maize Wheat Defat. Soya	25 70 5	Bolivia (1970-80)	Kansas State Univ.	Industrial	Pregelatinized maize flour	Fellers 1983
Maize (semolina) Wheat	20-40 60-80	Togo (1982)		Industrial		FAO 1983
Maize Wheat Soya	15 82 3	Ecuador		Industrial		Salazar and Riveros 1982
Maize	100	France	IRAT/INRA, France	Pilot	Pregelatinized retrogradated maize flour	CIRAD/IRAT 1986
Rice Maize Millet	NS	India	Hindustan Lever Research Center	Laboratory		1987
Wheat Mize or rice	NS	Switzer-land	Bühler Bros	Pilot	Good quality	1986
Soft wheat Flour	50 50	Italy	Yugoslavia and Italy	Pilot part of MILATOVIC	Maize was pregelatinized	Milatovic, Pavan 1986
Triticale Sorghum or millet	NS	Italy	National Institute of Nutrition	Pilot	Pregelatinized satisfactory	Cubadda 1987
Rice Maize	100 100	Nether-lands	TNO, Netherlands	Pilot	Extruded flour good quality	Kim 1987

1. Wheat = durum wheat. 2. NS = Percentages not specified. 3. Not available.



A = Waste
B = Stones/earth
C = Dust
D = Bran/germ
E = Flour
F = Bran/germ

1 = Intake elevator
2 = Mill cleaner
3 = Automatic weigher
4 = Dry stoner
5 = Centrifugal dust collector
6 = Vertical shelling machine
7 = Aspiration unit
8 = Elevator, double
9 = Plansifter, double
10 = Air sifter
11 = Asima mill-type grinders
12 = Filter unit
13 = Buffer bins

Figure 1. Diagram of a sorghum mill.

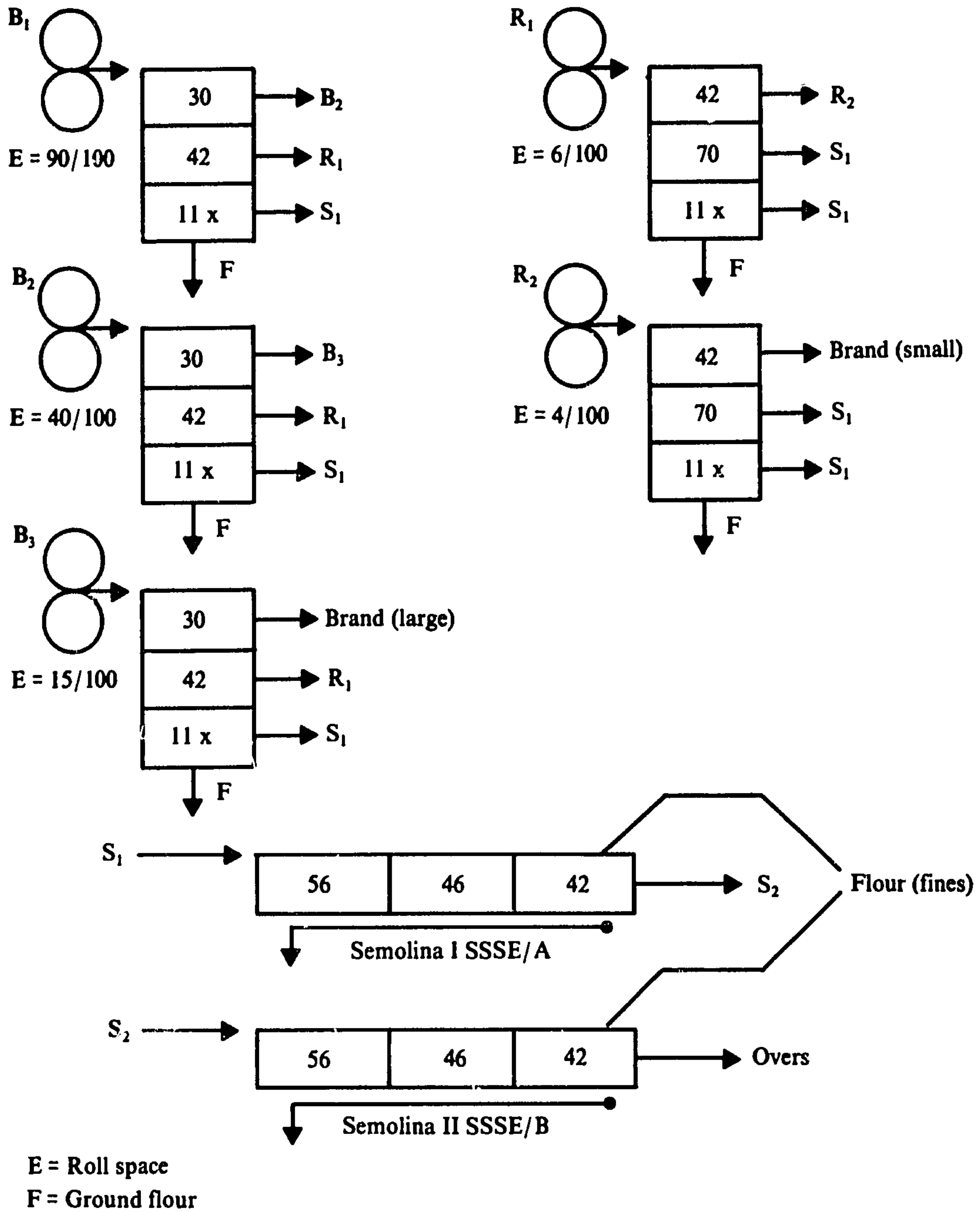


Figure 2. Durum wheat milling diagram adjusted for production of sorghum semolina (Abecassis et al. 1978).

Technology for Sorghum Pasta Production

Gluten proteins contribute to dough formation and plasticity, to cohesiveness during extrusion, and to the drying of pasta. They also prevent desegregation during cooking. Being specific to wheat, they are not present in maize and sorghum. The problem confronted by the absence of gluten proteins has been addressed by various methods, bearing in mind that the industrial technology of pasta should not be significantly modified.

Sorghum Pasta

Flour gelatinization

Gelatinization occurs at about 77°C, when heat treatment is applied to sorghum semolina at a level of hydration of 50% water and above (Miche 1978). Procedures to gelatinize sorghum grits or flour are described using a roll or extrusion cooker and hot water in a steam mixer (Anderson et al. 1969, Miche 1978). Considerable literature has been published on maize gelatinization.

Although pregelatinized 100% sorghum-made pasta had good cohesiveness and kept well after drying despite general translucence and vitreousness, the pasta disintegrated during cooking. Retrogradation of the gelatinized starch network in the extruded pasta may reorganize a modified structure, thereby improving its cooking behavior. However, retrogradation has not yet been studied on sorghum or maize flour.

Additives

The use of additives and monoglycerides has been tried without noticeable success on cohesiveness and cooking qualities of sorghum pasta (Miche 1978).

Partial gelatinization of starch or flour

Nonwheat pastas like Chinese noodles and dietetic pasta products are manufactured by blending untreated flour with gelatinized starch or flour. The process was applied to sorghum and maize by Miche et al. (1977).

Addition of wet or dried pregelatinized starches gave good results with solid losses in cooking lower than 8% dry matter basis (Table 4). Starches (maize starch in particular) gave better results than corresponding flours. However, the use of 25% starch in pasta is uneconomical on an industrial scale and the lower protein content of the product may be inappropriate in developing countries.

Table 4. Use of pregelatinized starches in sorghum pasta.

White sorghum, Senegal (75%)	Cooking losses dry matter basis (%)	Color	
		Brown[1]	Yellow[2]
Corn starch 25%	2.9	29	11
Corn flour 25%	3.9	29	26
Wheat flour 25%	7.6	27	13
Wheat starch 25%	7.6	28	14
Rice starch 25%	4.5	30	12
Wheat pasta 100%	5.7	18	18

1. Brown index = 550 nm reflectance.
2. Yellow index = 480 nm reflectance.

Source: Miche et al. 1977.

Another product was developed by Miche (1977) using 25% drum-dried flour and 75% untreated flour of less than 125 μ (Fig. 3) (Miche et al. 1977). Cohesiveness after extrusion and drying characteristics were similar to durum pasta, and cooking losses and color were acceptable. The need to gelatinize 25% of the flour, however, may increase production costs significantly.

Sorghum/Wheat Pasta

An alternative and probably more convenient method of producing pasta with sorghum at a significant rate of incorporation is to use wheat proteins to improve cooking behavior. Results were satisfactory up to 50% sorghum flour (Table 5). Similar tests were later conducted with reground maize grits. Losses were two to three times higher than with sorghum at the same rate of incorporation.

Further Developments

Drying temperatures now used in modern pasta plants are high (70°C) or very high (90°C) and drying time is reduced from 15 h to 5 h. It would be of interest to study the influence of high temperature on cooking

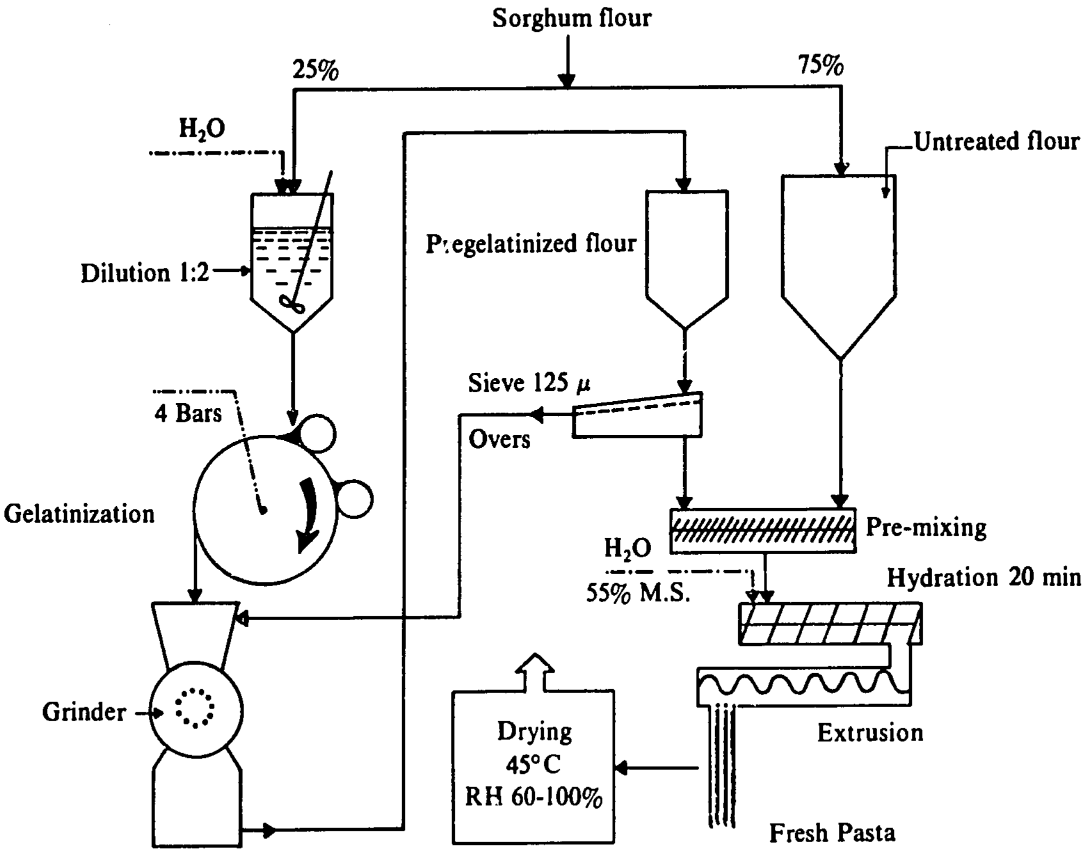


Figure 3. Processing of sorghum pasta (Miche 1976).

Table 5. Influence of wheat : sorghum ratio on cooking quality.

Composition			
Wheat Semolina (%)	Sorghum flour[1] (%)	Cooking Losses 18 mn (%)	Appearance[2]
100	-	5.7	10
80	20	7.8	9
60	40	6.8	7.5
50	50	7.4	7.5
30	70	7.8	3.5
20	80	10.8	2

1. Sorghum S 29 from Burkina Faso (horny endosperm, white pericarp, no colored testa).
2. Appearance scale of 1-10.

Source: Miche et al. 1976.

qualities of sorghum pasta and sorghum/wheat pasta with increasing rates of sorghum flour.

By heating dried pasta (12-13% water content) at 90°C, the cooking quality of durum spaghetti was improved, and more recently this heat treatment also had a positive effect on maize/wheat pasta (Table 6).[1] The impact of this treatment on sorghum pasta remains to be studied.

Further research required to produce pasta with a significant amount of sorghum includes studies on adjustment of sorghum flour, granulometry, hydration conditions, and extrusion pressure. The biochemical aspects of amylose and protein characteristics (kaffirine in particular) should also be considered. However, color remains the limiting factor with sorghum. Brownness is linked to the color of flour and the oxydase activity during the manufacturing process.

1. Submitted for publication Jan 1988.

Table 6. Influence of heat treatment on cooking qualities of pasta products (maize/durum 70/30).[1]

	State of surface[2]		Cooking losses (%)	
	Normal[3]	Head Treated[4]	Normal	Heat Treated
Spaghetti	4.2	4.5	26	13
Macaroni 8 holes	5.0	5.6	14	10
Macaroni 2 holes	5.0	5.6	15	9

1. All products were dice-shaped.
2. Scale: 1 = very poor, 9 = excellent. Durum wheat spaghettis are usually rated 6-7.
3. No treatment during drying.
4. Heat-treated for 2 hours at 90°C, 78% relative humidity at the end of drying stage.

The research program currently undertaken at the INRA/IRAT Cereal Technology Laboratory is now focused on maize/wheat pasta (70/30), mainly because its color is more acceptable. Yellow maize from Europe and white maize from West Africa were used, and acceptability tests were conducted in Senegal in Mar 1988.

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Discussion

R. Schaffert: Has any work been done to evaluate the varietal differences of food type sorghums on the industrial quality and industrial process?

J. Faure: There have been only a few industrial trials in the past and none at the moment. Differences from one sorghum to another are essentially due to the origin (either floury or vitreous) of the flour used. Poor color remains the main varietal difference. On biscuit and extruded products, trials were made in the Netherlands 10 years ago, but not published, and only on two or three varieties. On pasta, we conducted trials on three varieties. The hydration rate is the main difference. Floury grains achieve high hydration faster than vitreous endosperm grains, but the final levels are similar.

Recent Experience on the Milling of Sorghum, Millet, and Maize for Making Nonwheat Bread, Cake, and Sausage in Nigeria

O. Olatunji, O.A. Koleoso, and A.B. Oniwinde[1]

Abstract

The colossal drain in foreign exchange from wheat imports, coupled with reduction in the Nigerian government's foreign exchange earnings, resulted in the banning of wheat imports in 1987 and the search for local alternatives. Sorghum, millet, and maize were dry milled to different particle sizes of flour and used in making 100% nonwheat bread, cakes, and sausages. Flour of 300 µ gave the best bread, while flour of 150 µ gave the best cakes and sausages. Bread loaves from the 100% nonstarch wheat flour were slightly brittle, and detoxified cassava starch was added to improve its crumb texture. The blend of 70% nonwheat flour–sorghum or millet—with 30% cassava starch gave bread and confectionary products of better quality. Products made from sorghum were more acceptable than those from millet. The peculiar characteristics of the nonwheat flour, especially the lack of gluten, necessitate the modification of the present method for using wheat flour. The paper also discusses previous experiences in Nigeria with wheat composites and the beneficial effect of the recent changeover.

Background

Nigeria has developed an increased tendency towards bread consumption. A few decades ago, bread was not an item of daily diet of Nigerians. Kilby (1965) suggested that it was first introduced to Nigeria by freed Afro-Brazilian slaves in 1835. In those days bread was regarded as a luxury food for the elite. However, its consumption increased very rapidly because of its convenience, cheapness, and availability. Within a short time it gained prominence as one of Nigeria's staple foods.

Up to the present, bread and other baked products were produced from 100% wheat flour. Nigeria unfortunately cannot produce wheat for commercial use because the climatic and soil conditions are unsuitable for wheat cultivation. Hence all the wheat required to satisfy local demand for bread and confectionary products must be imported.

Government Policy

Statistics indicate that the costs of wheat imports in the 1970s increased more than twelvefold in the 1980s. In the face of dwindling foreign exchange, coupled with the enormous increase in the cost of wheat importation, the Federal Government banned the importation of wheat on 1 Jan 1988. To sustain the demand for bread consumption in Nigeria, alternative non-wheat flours were needed for breadmaking and confectionary products. It is pertinent to recall that as far back as 1969 the Federal Institute of Industrial Research in Oshodi, Lagos, started research on the

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Olatunji, O., Koleoso, O.A., and Oniwinde, A.B. 1992. Recent experience on the milling of sorghum, millet, and maize for making nonwheat bread, cake, and sausage in Nigeria. Pages 83–88 *in* Utilization of sorghum and millets (Gomez, M.I., House, L.R., Rooney, L.W., and Dendy, D.A.V., eds.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

gradual substitution of wheat with nonwheat flour, referred to as composite flour.

Composite Flour

Composite flour is wheat flour blended with nonwheat flours made from maize, cassava, sorghum, millet, or soybeans. Considerable information exists on composite flour (James et al. 1973, Olatunji et al. 1978, Olatunji et al. 1980). We have established four specific findings since the early 1970s.

1. Up to 30% cassava starch mixed with strong wheat flour in the presence of a dough improver (1% glycerol monostearate) gave acceptable bread.
2. Up to 20% cassava starch, 5% full fat soy flour, and 75% strong wheat flour made equally good bread.
3. Good quality bread can be baked with blends containing either 20% sorghum or 15% maize flour. Higher substitution levels were found possible with the use of improvers.
4. Higher substitution levels up to 55% made acceptable biscuits, cakes, *chin-chin*, doughnuts, and pastries with as good if not better texture and eating quality than that from 100% wheat flour.

One of the major prospects of this kind of partial substitution could have been a decrease in the level and amount of imported wheat. The advantages of this research were never realized because it took the flour millers a long time to accept the new concept.

By the time the millers finally accepted the composite flour concept, the Government had placed a total ban on wheat imports. This decision meant that imported raw materials had to be replaced with local alternatives. In compliance with the new concept, the Institute changed its research program on wheat composite to nonwheat composite flour.

Nonwheat Composite Flour

The replacement of wheat flour with locally produced products such as cereals, root crops, and legumes is in line with the thinking of FAO. Kim and De-Ruiter (1973) reported that although partial substitution of wheat flour by nonwheat flour saved some foreign exchange, it was not the ultimate goal. For most countries the goal is the virtual elimination of the need for wheat and wheat flour importation for breadmaking.

Raw materials for nonwheat flour

Nigeria grows staples that can substitute for wheat. These are grouped as follows.

1. Cereals (maize, millet, sorghum, rice)
2. Roots and tubers (cassava, sweet potato, yam)
3. Oilseeds (groundnut, cottonseed, soybean)

Cereals. Maize is the most widely grown crop in Nigeria. The crop's greatest production potential is in the savannah ecological zone, although its traditional areas of production are in the wetter southern Guinean and forest zones. Rainfall in the forest region can sustain two crops per year.

The savannah zone can produce only one crop under rainfed conditions, but with supplementary irrigation two to three crops are possible. The current national production figure for maize is estimated at 2 million t per annum. The projected production is 7.5 million t by 1990.

Sorghum and millets constitute the most important cereals produced and consumed in Nigeria. Based on the survey carried out by the Consultative Committee on Grains, between 1981 and 1983 the average output of sorghum was 3.7 million t, and that of pearl millet was 2.7 million t. The Committee projected the potential of sorghum to be up to 9.4 million t by 1990, and that of millet 4.8 million t. The crops are grown in 11 states of Nigeria.

Roots and tubers. Cassava and yam are the two most important tuber crops produced in Nigeria. Cassava was grown in large quantities in 13 states with a total output of 34.2 million t between 1981 and 1983. The projected production is 21.3 million t in 1990.

Nigeria produces 12.14 million t yams annually in 15 states. Total production between 1981 and 1983 was estimated at 37.9 million t.

Oilseeds. Soybean, a high-protein grain crop, is an annual legume with great potential in Nigeria. Estimated production stands at about 0.075 million t per annum. It is grown in 14 states, including Abuja.

Processing

Cereals. The cereal grains (maize, sorghum, millet) are cleaned manually. The cleaned grains are conditioned, tempered, and debranned in grain hullers to remove the outermost fibrous layer. The operation also removes the germ (the oil-containing part of the grain). The grits obtained are cleaned and milled to the desired particle size using a hammer mill.

Roots and tubers. Cassava tubers are peeled and grated. The starch slurry is then detoxified to remove the cyanide content. The slurry is dewatered, dried, and milled to a fine powder.

Oilseeds. Soybeans are dried in Mitched air driers at 110°C for 1 h. The grains are then cracked using a plate grinder. The cracked grains are then separated from the bran by simple aspiration. The cleaned beans are boiled until soft, pressed hydraulically, and dried in the rotary driers at 150°C for about 30 min. The dried grains are milled using either Bühler roller mills or Apex hammer mills.

Breadmaking with Nonwheat Flour

The Institute has developed suitable recipes for nonwheat bread using 70% maize, sorghum, or millet flour, and 30% cassava starch. Other ingredients are added at the following percentages of total flour weight: 2% yeast, 1.5% salt, 10% sugar, 1% fat, 0.2% fungal amylase, and 80-100% water.

The dry ingredients are mixed for about 5 min before adding water, then mixed thoroughly for another 10 min to make a smooth paste batter. The batter is left in the bowl to ferment for 30 min, and then remixed for 10 min. The batter is placed into baking pans and proofed for about 20 min, then baked in the oven at 180-220°C for 50-60 min.

Cake and Other Confectionary Products

Nonwheat flour is particularly suitable for making cakes, following the same procedures as for wheat flour. The ingredients consist of 70% sorghum, maize, or millet plus 30% cassava starch. Other ingredients added as percentages of the flour are sugar (5%), fat (5%), eggs (5%), baking powder (6%), water (60-80%), milk (4%), and flavor (0.2-0.4%).

The ingredients are weighed and the sugar and fat mixed until smooth and light. The liquid eggs are then added and creamed until fluffy before adding the flour, milk, water, and flavor. The mixture is then mixed at slow speed to take up all the flour. The mixing speed is gradually increased to a medium speed for 5 min. The batter is poured into greased cake pans and baked at 180°C for about 30 min.

Investigation on the use of nonwheat for pastry has reached an advanced stage. However, the particle size of flour required for pastry is finer than that for bread. While flour with particle size of 300μ is desirable for bread, that for cakes and pastries is 150μ.

Assessment

Both bread and cakes were evaluated by 10 trained laboratory panelists in two separate sittings. They were assessed for attributes of color, taste, texture, and flavor using a six-point hedonic scale in which one was excellent and six was very poor. A seven-point hedonic scale was used for overall acceptability in which one was "like very much" and seven was "dislike extremely".

Summary of Research Results

The highlights of our research results are as follows.

1. The quality of the nonwheat bread is affected by the variety of cereals used. Also, the particle size of the nonwheat flour affected bread quality (Table 1).
2. The batter method gave better results than the dough method. Both maize and sorghum made acceptable bread, especially with a blend of flour consisting of 70% of the cereal flour and 30% of cassava starch.
3. Our initial trials showed that the crumb texture of sorghum bread was better than that of maize bread. Millet bread would have been the best of the three cereals but for the grayish color of the varieties used (Table 2).
4. Bulk fermentation improved the texture of the bread and is recommended. Maize, sorghum, or millet loaves were more compact than those of regular whole wheat bread of the same initial weight, largely because of the gluten content of wheat.
5. Improvers such as glycerol monostearate and full-fat soybean flour slightly improved the texture and freshness of the nonwheat bread. The best results obtained used fungal amylase, which significantly improved the texture of the nonwheat bread.
6. The keeping quality of nonwheat bread under normal room temperature is about 3 days. Work is ongoing on the use of improvers and additives to improve both keeping quality and freshness.

7. Because of their physico-chemical differences, nonwheat bread and whole wheat bread should be assessed on their own merit rather than compared with each other.
8. Trials with cakes and sausages gave good results. However, the problems with these products are insignificant compared with those of bread.

Table 1. Mean values of physical and sensory characteristics of nonwheat sorghum bread from different particle sizes.

Attributes	Particle size (μ) 150	300	425
Specific volume (cc g^{-1})	2.10	2.20	2.00
Color[1]	2.83	2.33	3.00
Rating	VG	VG	G
Texture[1]	3.83	2.50	3.00
Rating	G	VG	G
Flavor[1]	2.88	3.33	3.00
Rating	VG	G	G
Taste[1]	3.50	2.67	3.17
Rating	G	VG	G
Overall acceptability[2]	3.83	2.50	3.00
Rating	LS	LVM	LS

1. Six-point hedonic scale (1 = excellent, 6 = very poor).
2. Seven-point hedonic scale (1 = like very much, 7 = dislike extremely).

LS = Like slightly. VG = Very good.
LVM = Like very much. G = Good.

Source: Koleoso and Olatunji 1986.

Table 2. Comparative assessment of 100% sorghum, millet, and maize nonwheat bread.

Attributes	Maize	Sorghum	Millet
Specific Volume (cc g^{-1})	2.00	2.21	2.33
Color[1]	2.00	2.30	5.00
Rating[1]	VG	VG	VP
Texture[1]	2.67	2.23	2.00
Flavor[1]	3.18	3.33	3.58
Taste[1]	2.50	2.67	2.67
Rating	VG	VG	VG
Overall acceptability[2]	2.55	2.50	4.50
Rating	LVM	LVM	DVM

1. Six-point hedonic scale (1 = excellent, 6 = very poor).
2. Seven-point hedonic scale (1 = like very much, 7 = dislike extremely).

VG = Very good. LVM = Like very much.
VP = Very poor. DVM = Dislike very much.

Source: Koleoso and Olatunji 1986.

Commercial Test Production on Nonwheat Bread

Commercial production of both the maize/cassava and sorghum/cassava starch bread were carried out at commercial bakeries in Lagos, Kwara, and Kaduna. These trials were conducted to assess the suitability of existing commercial wheat breadmaking equipment for nonwheat bread. The recipes and procedures used were as previously established in the laboratory and pilot plant studies.

The results showed that for the majority of the bakeries, the existing equipment was suitable for baking nonwheat flour. The nonwheat bread produced was of the same quality as that obtained in the laboratory. There was no need for dough break and a divider because the batter method was used and no dough was formed. Although mixing with a spiral hook gave results similar to those obtained in the laboratory using the Kenwood mixer, modifications are probably necessary for different mixers.

It was also discovered that the quantity of water needed for mixing in the commercial bakery was about 10% less than on laboratory scale.

In our determined effort to make this technology available to all Nigerians, this Institute organizes regular training workshops for the use of nonwheat flour for baked products.

Production Prospects and Constraints

Flour mills

Existing wheat milling plants must be modified before they can be used for milling the local cereals. The total cost put forward for converting 50 units of 250 t each was estimated at US$ 0.8 million per unit, which is within the capability of the milling industries. One of the major advantages of the changeover to local cereals is that the equipment for processing them now exists in the country at reasonable cost.

The flour mills have now converted some of their wheat units to process local cereals. Many other organizations and individuals have installed equipment to process local cereals in line with recent Government directives. Fortunately, the costs of this equipment are lower than those of equipment for processing wheat.

Bakeries

The existing bakery equipment now in use for wheat is adequate for nonwheat bread, cakes, and sausages.

For breadmaking, however, some bakeries will have to change their mixers. The new processing method for making nonwheat bread does not require the use of the dough break and divider technique currently in use in the bakeries. A scaling device needs to be incorporated into the wheat bread line to reduce the rigor of weighing individual batter into the pan. Also the mixing bowl must be movable for smooth operation.

Market Testing, Acceptability, and Price

The reaction to the nonwheat products is mixed. While a good number of patriotic Nigerians accept the products, others oppose the change. The most vociferous are the bakers and millers because they fear (incorrectly) that they have to change all their equipment.

Market testing revealed that nonwheat products may gain wide acceptability once the normal wheat bread is removed from the market.

The current situation is that a 50-kg bag of wheat that sold for 18-25 Naira in 1985, 25-50 Naira in 1986, 50-120 Naira in 1987, now sells for up to 250 Naira. Even at such exorbitant prices the quality is very poor. The corresponding value for maize or sorghum is not more than 50-60 Naira. The price of wheat bread is now out of reach of low-income groups.

Conclusions

Sorghum, millet, and maize can be used to make acceptable nonwheat bread. The loaves are normally more compact than loaves of wheat bread. The current method of selling bread by volume must change.

Weight should be used as a yardstick for fixing the cost of nonwheat bread. Millet gave good quality bread loaves but the grayish crumb color renders the loaves unacceptable. For quick acceptability of nonwheat products, the bread loaves made from wheat flour should be removed from the market to allow people to get used to the new products. Both cakes and sausages made from nonwheat flour were acceptable and marketable.

The foreign exchange generated from the ban, the multiplier effect of new investments in agriculture, and the need to become self-reliant are sufficient to justify the change to local cereals for bread and confectionary products.

We believe that various improvements in the quality of the nonwheat products are still possible. We therefore ask other scientists to join hands with us through intensification of research in this direction. Breeders should also endeavor to develop breeds of sorghum, millet, and maize with improved baking qualities in such areas as color, binding properties, and good quality protein.

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Discussion

A. Carney: What were the specific volumes of wheat flour loaves compared with your new wheat flours which you showed at 2 to 2.5?

O. Olatunji: Depending on the quality of the wheat, 3 to 5.

A. Carney: Have you screened and selected varieties suitable for the nonwheat bread?

O. Olatunji: Varieties have been identified for maize, but we are still working on this for sorghum. Our preliminary results showed differences in baking quality.

L.R. House: Have you had an opportunity to look at pearly white-seeded pearl millet to improve the color in nonwheat bread made from pearl millet flour?

O. Olatunji: I have not had the opportunity to use white pearl millet in nonwheat bread. I am still searching for such a white variety. We expect color will be a problem, since millets give products with grayish color.

A.C. Moshe: Have you examined brown bread acceptability as a means of overcoming the color problem?

O. Olatunji: No. Brown bread is not accepted. Brown bread has no wide acceptability such as white bread because of the color difference. However, those informed on the nutritional advantage of brown bread do accept them.

T. Ndoro: What is the shelf life of the product compared with that of wheat? What is the nutritional value of the product?

O. Olatunji: The shelf life of nonwheat bread is about 3 days under normal room conditions. For wheat bread it varies from 3 to 4 days with the current quality of wheat flour in Nigeria. The nutritional value is not significantly different from wheat bread. It has slightly more calories because of the higher sugar content and slightly lower protein content. The addition of defatted soybean flour could make up the reduction in protein.

The Potential for Extruded Sorghum Food Products in Zimbabwe and the Regional Market

P. Chigumira[1]

Abstract

In recent years, substantial interest has been shown throughout the world in the production of nutritious blended foods as weaning foods, as supplements for pregnant and lactating mothers, and for feeding schoolchildren or other groups with high nutritional requirements. Nutritious foods for these purposes can be made from a mixture of locally grown cereals, oilseeds, and legumes. Private companies in Zimbabwe and other countries in the SADCC region are searching for new ways to stimulate their businesses. In food processing, extrusion cooking provides a great opportunity to create new and exciting products. Extrusion cooking can be utilized in the developing countries to convert indigestible cereals to products that are both digestible and palatable. Following the acquisition of the Brady Extruder in 1981, Willards Foods Limited developed a range of blended foods, powdered nonalcoholic beverages (mahewu), *and instant maisoy-sorghum puffed flakes. The demand for sorghum-based extruded products, however, is limited by price, quality, and culture.*

Introduction

Historical

Sorghum probably originated in North Africa about 3000 BC. It was certainly cultured in Egypt by 2200 BC, according to wall paintings of that period (Kent 1983). From there it spread throughout Africa and to India and the Middle East. It reached China and America more recently.

Utilization

Sorghum is a staple food in many parts of Africa. It is an important beverage—both alcoholic and nonalcoholic—in several countries. Of the total world sorghum production of 64 million t in 1978, approximately 61% was used for human food and 39% for animal feed and industry (Kent 1983). According to the FAO provisional balance sheets for 1975-77, human consumption of sorghum flour was 5 kg per capita per year in Zimbabwe. This is very low compared with other African countries where consumption was 20-30 kg per capita per year for the same period.

During the 1983-87 period, the volume of sorghum from Zimbabwe's large commercial producers increased significantly. Similar increases were also reported by small-scale commercial and communal land producers. Purchases by Zimbabwe's Grain Marketing Board during the 1986/87 season increased by nearly fivefold over the 1983/84 figures,

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Chigumira, P. 1992. The potential for extruded sorghum food products in Zimbabwe and the regional market. Pages 89-94 *in* Utilization of sorghum and millets (Gomez, M.I., House, L.R., Rooney, L.W., and Dendy, D.A.V., eds.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

while total grain purchases over the same period increased by only 37%.

Table 1. Grain Marketing Board intake and sales of sorghum during the 1984-87 period, in tonnes.

Year	Intake	Total sales
1984/85	20 672	14 163
1985/86	82 013	34 941
1986/87	70 304	24 988
Total	**172 989**	**74 092**
Local sales/intake	33.3%	
Total sales/intake	42.8%	

Source: Grain Marketing Board 1986/87.

Table 1 shows Grain Marketing Board intake and sales of sorghum for the period 1984-87. The Grain Marketing Board is presently holding approximately 81 000 t of sorghum, well in excess of its annual sales. Special points to note are:

- surplus grain is expensive to store; and
- malnutrition problems have been reported in certain parts of Zimbabwe and other SADCC countries, particularly among infants and school-children.

Uses of Sorghum

Traditionally, sorghum is used for:

- brewing (opaque beer—the principal use of sorghum);
- stockfeed mixtures; and
- porridges—thick (*sadza*) and thin (*bota*).

Other uses such as composite flour for baking and pasta production and extruded foods have not yet been fully exploited in Zimbabwe. Over the last 3 years the Zimbabwe Government has therefore encouraged the use of small grains. The Small Grain Working Group was started in Mar 1985 under the auspices of the Ministry of Agriculture to investigate the production, processing, consumption, and storage of small grains and to make recommendations concerning increased small grain utilization.

Willards Foods' research objectives were:

- to launch new extruded sorghum products and extend its range of sorghum-based products to secure a share of a potentially large market;
- to respond to the Government's call to develop products to address the country's malnutrition problems; and
- to partially substitute maize with sorghum in our range of extruded products.

Extrusion Cooking

With the increase in business pressure, companies are searching for new ways to market their products. In the food processing business, extrusion cooking provides an opportunity to create new products and to improve existing ones. Extrusion cooking can be utilized in developing countries to convert indigestible cereals into products that are both digestible and palatable.

Following the acquisition of the Brady Extruder® (75 hp, Model 206, USA) in 1985, Willards Foods developed a range of blended extruded foods made from mixtures of locally-grown cereals and protein materials and fortified with essential vitamins and minerals.

Products Developed

Extruded instant *mahewu*

Traditionally, *mahewu* is a fermented, sour, non-alcoholic beverage based on maize meal. It is popular throughout southern Africa. Our instant *mahewu* was made by extruding a mixture of maize meal, ground sorghum, and soya flour. The extruded flakes were milled and mixed with sugar and malic acid to simulate the natural souring in the traditional products. Sorghum levels in the formulations were as high as 35%. Two products, high energy and high protein, were launched.

Extruded maisoy/sorghum flakes

These are nutritious ready-to-eat high-protein products. The flakes can be eaten dry or mixed with water or milk. Four products were developed: natural, fish, beef, and milk flakes—all sweetened.

Tables 2 and 3 show the nutritional profiles of some of the products developed by Willards Foods.

Table 2. Analysis of powdered *mahewu* (per 100 g).[1]

Protein	17	g
Fat	3.5	g
Carbohydrates	67	g
Calories	365	K cal.
Iron	25	mg
Vitamin A	3000	I.U.
Vitamin B_1	0.3	mg
Vitamin B_2	0.19	mg

1. Product was fortified with vitamin A and iron.

Table 3. Analysis of maisoy/sorghum beer (per 100 g).

Protein	20 g
Fat	4.4 g
Fiber	2.0 g
Calories	388 K cal
Calcium	250 mg
Phosphorus	400 mg
Iron	6.5 mg
Beef flavor	1.0 g

Product Distribution Strategy

The products were intended for distribution to mines, hospitals, retail outlets, and food aid agencies (such as Freedom from Hunger, UNESCO, and the International Red Cross). To test the retail market, we developed a nutritious, high-protein, pronutro-type puffed flake product containing sorghum. The product, which also contains other cereals, oilseeds, milk solids, flavorings, vitamins, and minerals, was specially formulated to meet 50% of the essential daily vitamins and calcium needs in each 50-g serving.

Product Distribution

Because the research and development taste panel results and the market survey results both showed significant acceptability, the maisoy product was launched. Initially, sales were good. After several months, however, profits started to decline as production far exceeded sales volume.

Extruded instant *mahewu* was sold mostly through the mines and maisoy/sorghum flakes through food aid agencies.

A supplementary feeding scheme undertaken by the Voluntary Organisation in Community Enterprise (VOICE) in the Rushinga District in 1983/84 using extruded *mahewu* and maisoy/sorghum flakes showed a marked improvement in children's health. VOICE's Newsletter no. 3, 1984 reported: "Since the scheme started we haven't seen any diseases, diarrhoea or stomach troubles. The children have totally accepted the new diet."

The demand for these extruded products, however, was generally low. The extruder was therefore operated at the unprofitable level of 50% capacity, and both products (maisoy and *mahewu*) were subsequently discontinued.

Advantages of Extrusion Cooking

1. Gelatinization of starch enhances digestibility.
2. Partially denatured protein enhances digestibility.
3. Thermally labile growth inhibitors such as trypsin inhibitor are inactivated.
4. Rapid inactivation of enzymes such as lipases and oxidases enhances storage stability of processed foods.
5. Natural toxicants (goitrogens, hemagglutinins, cynogenetic glycosides, etc.) are destroyed.
6. Micro-organisms are reduced or eliminated.
7. Instantized products can be prepared quickly, thus saving time and equipment.
8. Cooking time is dramatically reduced, thus enhancing the vitamin content and nutritive value of the food. Extrusion is a high temperature short time (HTST) process and nutrients are more sensitive to time than temperature compared to micro-organisms.
9. Extrusion-cooked foods are shelf-stable, thus ensuring nutritious food all year.
10. Fuel costs associated with normal lengthy cooking are reduced. The processing costs of extrusion cooking systems are lower than those of drum drying systems. Our cost analysis shows that energy/power costs for extrusion cooking are \$0.02 kg^{-1} compared to \$0.21 kg^{-1} for drum drying systems.

Extrusion

Maize meal, ground full-fat soya, and ground sorghum were mixed in a ribbon mixer. Grain cereals (maize and sorghum) and soya had an initial moisture content of ±10%. Sufficient cold water was added to bring the moisture content of the milled ingredients to 13-15% after mixing, but before initiating the extrusion process.

In the three experiments, the level of full-fat soya flour was kept constant at 5%. Levels of sorghum were 0%, 20%, 40%, and 95%. The tempered ingredients were fed into the extruder through a live bin and a screw auger feed system. Figure 1 shows the flow diagram of the extrusion process.

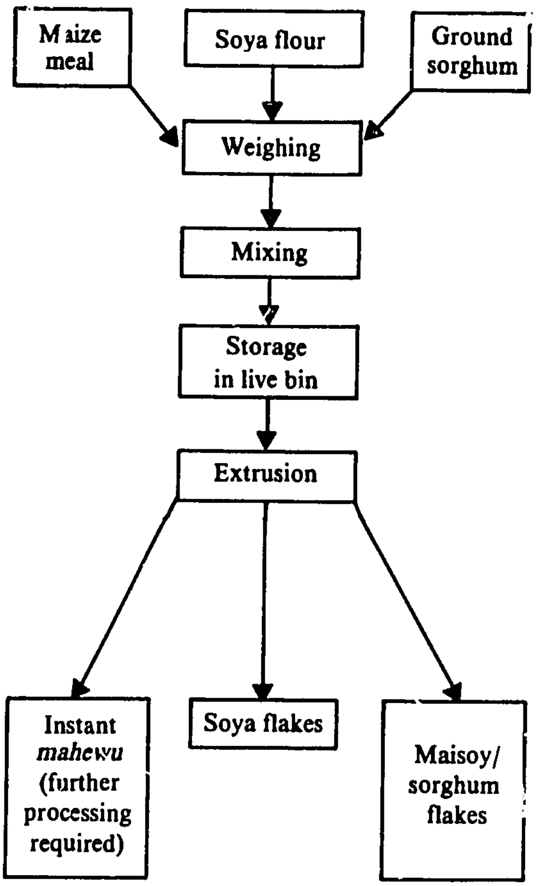

Figure 1. Flow diagram of the Brady Extrusion Process.

After extrusion, moisture content of the final flaked product was 4-6%. For instant *mahewu*, the flakes were milled using a Collins mill fitted with a 1-mm screen. The milled product was mixed with sugar and malic acid and mixed thoroughly in a ribbon mixer.

Extension experiments were conducted with the red sorghum variety. Extruder operating conditions were:

T_b = 58°C maximum; and
T_f = 135-140°C

where: T_b = temperature at the back of the extruder (i.e., raw material inlet); and
T_f = temperature at the front of the extruder (i.e., product exit).

Machine performance with 40% or more sorghum flour in the formulation was poor. Extruder temperature overheated and had to be adjusted frequently. The rotor or screw wore out too quickly (Table 4). A cost comparison is given in Table 5.

Table 4. Extrusion characteristics—formulation comparison.

Composition	Machine performance	Product quality
Maize/soya 95% 5%	Good	Well expanded, good flavor, texture, and color
Maize/soya/sorghum 75% 5% 20%	Good	Well expanded, acceptable texture
55% 5% 40%	Medium	Some expansion, gritty texture, unacceptable color, and flavor
Sorghum/soya	Poor	Slightly expanded
95% 5%	Excessive machine wear	Bitter flavor, poor color, sandy texture

Table 5. Formulation cost comparison (raw materials only).

Formulation	Cost (US$ kg^{-1})
Maize/soya 95% 5%	0.3925
Maize/soya/sorghum 75% 5% 20%	0.4033
Maize/soya/sorghum 55% 5% 40%	0.4150
Sorghum/soya 95% 5%	0.4458 + 14%

Problems in Sorghum Utilization

Price versus nutrition

Sorghum grain costs \$239 t^{-1} compared with \$222 for whole maize. By the time the grains are processed by millers, the price is \$367 for sorghum meal and \$320 for maize meal, a price ratio of 1:1.5 (maize:sorghum). Thus sorghum meal is 15% more expensive than maize meal and malt sorghum meal is 60.8% more expensive.

Sorghum has no nutritional advantage over maize. Like maize, sorghum is deficient in lysine and tryptophan (Kent 1983). Sorghum resembles maize in composition and in feeding value (Topps and Oliver 1978). Further, polyphenols in sorghum have been reported to complex with proteins, reducing the biological value (House 1987). There is therefore no cost advantage in replacing maize with sorghum in formulations.

Quality parameters

The quality of food made from sorghum varieties is an important factor in consumer acceptance and market value.

Color. People in certain parts of Zimbabwe do not like the red color imparted by red sorghum to food. The white variety could overcome this color problem, but research has shown that some white sorghum strains develop a grayish/brownish color when cooked which may reduce its acceptability. Little research work was done at Willards with the white variety. The quantity of white variety sorghum grown in Zimbabwe is small, mainly because it is not bird-resistant and therefore uneconomical for the farmer to grow.

Flavor. Red sorghum formulations impart a disagreeable flavor above certain levels. This flavor was described as "funny" to "bitter" by panelists. The bitter taste has been reported by various investigators as due to tannin content (Kent 1983, House 1987). Kent (1983) reported that tannins can be activated by chemicals such as polyethyleneglycol.

Texture. Sorghum imparts a gritty to sandy texture to products. We analyzed the sorghum used at Willards in our extrusion experiments and found that the sorghum actually contained sand particles. We believe that this constraint may be overcome by improving the Grain Marketing Board's screening/grading techniques.

Ignorance/cultural problems

In our extensive consumer survey we found that sorghum-based products are regarded as lower-class products. Traditionally, the poor have grown sorghum and other small grains such as millet because they are are drought resistant and can be used to brew beer for sale. Because maize has been regarded as a crop for richer people, consumers must be educated to accept sorghum-based products.

Conclusion—What Is Required

1. Input from plant breeders concerning quality and nutritional traits are important in the selection criteria. Plant breeders need to select for desirable traits, such as extrusion characteristics, good flavor and color, good malting and baking characteristics, and high nutritional content (i.e., high-lysine varieties).
2. Greater interaction between plant breeders, university researchers, and industrialists is crucial. Research undertaken by any one sector in isolation could be a waste of time. A collaborative attitude is needed. It should be a chain consisting of three links: the researcher, the manufacturer, and the consumer.
3. Consumer education is important to encourage acceptance of sorghum-based products.
4. Government policy must become more supportive of sorghum research, and price structures should be reviewed. It may be advantageous, for example, to deregulate sorghum and allow it to find its own market.

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Discussion

J.M. Chitsika: You are proposing deregulation of sorghum so prices become more favorable for industrial processing. Without Government intervention how can sorghum compete with subsidized maize?

P. Chigumira: If sorghum sells at the same price as maize, there will be no problem. I am not certain about the comparative inputs for maize and sorghum production and the effect on price.

J.E. Cecil: If there were no Government intervention, how would the sorghum price compare with that of the maize?

P. Chigumira: Considering the high processing losses and handling costs, the food industry would like sorghum meal to be 90% of the price for maize meal.

J.E. Cecil: What are production costs and yields of sorghum relative to maize?

A.R.H. Hawke: Production costs of sorghum in the communal sector are less than for maize because little or no inputs are used, whilst inputs are used more and more in this sector for maize. The inputs for maize are also greater than those for sorghum in the commercial sector, but commercial producers won't like growing white sorghum due to damage by birds. Finally, the comparative yields of sorghum against maize in both sectors must be considered in assessing costs. The current sorghum price is Z$ 281 t^{-1} while that of maize is Z$ 220 t^{-1}.

L.R.House: We strongly feel that industrialists, food technologists, and breeders need a much higher level of communication than has previously existed. I hope that this will change soon. The yield capacity of maize and sorghum is about the same. We need to develop good sorghum hybrids to compete with hybrid maize.

About 70% of the sorghum grown in the SADCC area is white-seeded. I feel the bird problem is overrated and usually is not severe where large areas are sown.

P. Chigumira: The data on white varieties show that the bird problem exists and is a big threat. More work needs to be done here.

S. Ndoro: The production costs of sorghum in commercial areas are lower than those of maize, but the yield factor is too low to make the crop economical from the producer's point of view.

A. Carney: Economics affect milling usage as well as the products. Another comment is that varietal characteristics are important, and it appears we should purchase and store by variety, which is not possible at present.

P. Chigumira: I agree with these comments.

S. C. Muchena: What research work is Willards doing on pearl millet utilization?

P. Chigumira: None. All our research work has been with red sorghum, largely because this is what is available in excess at the Grain Marketing Board. The only sorghum product being commercially produced by Willards is Maltabella, a drum-dried breakfast cereal.

A. Moshe: How do we get people to use sorghum and how do we sell the idea?

P. Chigumira: People start using sorghum without the prerequisite variety selection, and when they face problems with process or product, use is abandoned. This would not happen if the breeders were consulted on the selection of varieties for a specific end-use.

The Use of Sorghum for Food in Brazil

R.E. Schaffert[1]

Abstract

The potential demand for composite flours in Brazil is great because the consumption of wheat is greater than production. The low cost of imported wheat after the Second World War contributed to a change in the eating habits of Brazilians, substituting many traditional foods for products made with wheat flour. Since 1976 the Government has spent approximately US$1 billion annually on importing and subsidizing the consumption of wheat. EMBRAPA has developed technologies for the preparation and use of several composite flours, including the production and use of a composite sorghum flour. Many products have been made, tested, and accepted in various regions of Brazil. A composite flour made from sorghum is superior to that of maize for some products, because maize flour alters the color and taste of the end product and sorghum flour does not. The use of composite flours in Brazil is technically viable, but it has not been economically viable because subsidized wheat flour costs less. In 1987 the subsidy of wheat was removed, and this triggered the use of several composite flours. There appears to be a demand for sorghum for human consumption in the semi-arid Northeast of Brazil. The national Maize and Sorghum Research Center of EMBRAPA is currently developing new white, vitreous-seeded sorghum cultivars suitable for human consumption.

Introduction

Development of food-type cultivars

Grain sorghum production in Brazil is still quite recent. The crop is sown on approximately 500 000 ha and averages yields of nearly 2 t ha^{-1}. Expansion of sorghum in Brazil is expected to occur in the semi-arid areas, particularly in the Northeast, the frontier region of southern Brazil, and in central Brazil in a doublecropping system following soybeans and other crops. In these regions sorghum matures during periods with little precipitation and low humidity, thus providing a good physical quality grain fit for human consumption.

The sorghum cultivars available in the Northeast are varieties and those in central and southern Brazil are hybrids. All the commercial hybrids in Brazil have red grain without tannin, with the exception of three high-tannin hybrids normally sown in the South. The varieties used in the Northeast are white-seeded with red color.

Diseases, principally anthracnose and rust, that constrain sorghum production in Brazil, are apparently quite different from those of other regions of the world. Consequently, the white-seeded food-type elite lines available for making hybrid combinations have not been well adapted to Brazilian conditions. In our breeding program, several experimental food-type sorghum hybrids have been made and evaluated without satisfactory results.

Development of food-type hybrids

One objective of our breeding program is to transfer the principal genes that control the quality factors to

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the elite lines currently used to make commercial hybrids. The principal characteristics we are transferring have thin white pericarps, tan plant color, large seeds, and vitreous endosperm.

Dr Ahmed El Dash of the Food Technology Research Center of EMBRAPA at Rio de Janeiro has cooperated with our breeding program, determining milling yields, flour color, flour quality, and end product quality. Within a few years, we hope to develop food-type derivatives of our elite hybrids as well as new food-type sorghum hybrids. We are currently testing two white-seeded red plant color hybrids that yield very well with good anthracnose and rust resistance. We expect to release these hybrids in 1989 or 1990. One of the hybrids (CMS × S 350) has no testa or seed coat and no tannin. We need a wider evaluation of the hybrid to confirm its apparent resistance to birds.

In the regional trials for the semi-arid Northeast, we have identified one variety with good potential (SPV 475), that has white vitreous seed and tan plant color. This cultivar was introduced and selected by the Agriculture Research Agency in the state of Pernambuco. The variety currently recommended in the Northeast is a dual-purpose white-seeded red-plant color selection identified as IPA 1011. A small pilot milling plant has been installed at Serra Talhada in the interior of Pernambuco with a production capacity of 3 t flour per week. This flour is being consumed locally in the form of a composite flour by the local baking industry.

Principal Factors Limiting Use of Composite Flour

The principal limiting factor in the use of composite flours in Brazil today is the subsidy on the consumption of wheat flour. In order to encourage the use of composite flour, its cost must be reduced, its quality improved, or be the only type of flour available. In Brazil, the subsidy on wheat flour was removed in 1987 when the price ratio of wheat flour to other flours was increased from about half to about double, opening the road to the use of a wide array of composite flours. However, the government began to subsidize wheat flour again during a period of high inflation, and currently wheat flour is less expensive than other flours.

During the interval with no wheat subsidy, several large commercial bakeries began using composite flour mixtures at rates of 10-15% with good consumer acceptance. By Jan 1988, however, the use of composite flours was nearly terminated, as the wheat subsidy consisted of about half the total cost. Consequently, the use of composite flours in Brazil decreased due to Government policy and not due to technical restraints.

Sorghum Price

The minimum price for sorghum established by the Government is 80-85% of the minimum price set for maize. This is a good policy for the expansion of sorghum in Brazil because it allows for a reasonable price to be paid to the producer and stimulates the demand for sorghum grain, especially in the food industry. Normally sorghum grain has a biological value 95% that of maize. Consequently, at a price of 80-85% the price of maize, grain sorghum becomes very attractive. Because of this pricing policy, the demand for sorghum by the food industry is greater than the current supply and there is little sorghum available for making a composite sorghum flour.

Another factor limiting the use of sorghum in composite flour is the lack of a sorghum flour milling industry. In Brazil, industry currently produces composite flour from maize and cassava flour.

Conditions Necessary for Commercial Use of a Composite Sorghum Flour

Today in Brazil, there are four prerequisites for using a sorghum composite flour on a regional or national scale.

1. The elimination of the subsidy on wheat.
2. The availability of an adequate white-seeded tan plant color cultivar.
3. A sorghum flour milling industry.
4. A favorable price ratio compared with other types of composite flours.

I believe that all four of these prerequisites could be satisfied in 1-2 years, especially in the Northeast.

One factor limiting the use of sorghum as a food crop for the Northeast is the preference for maize. Even though a huge deficit exists in maize production in the Northeast, maize is much preferred to sorghum. *Couscous* is a traditional Northeastern dish prepared from maize—the more intense the yellow color the higher the consumer acceptance. Sorghum, however, normally outproduces maize 2-3 times in the Northeast.

Conclusions and Recommendations

The use of a composite sorghum flour to replace imported wheat flour in Brazil is both technically and economically possible, provided the subsidy on the consumption of wheat flour is eliminated. Research should continue to emphasize developing agriculturally acceptable cultivars for the different regions of Brazil. A slight modification in the equipment used to mill wheat grain should also improve the milling of sorghum. A continuation of a minimum price system with the price of sorghum between 80 and 85% of the minimum price of maize should be adequate to increase the sorghum hectarage in Brazil to meet demand for both the food industry and the composite flour industry. Technology should be also developed to process sorghum flour near the farms to reduce transportation costs.

Discussion

J.E. Cecil: What is done with stillage in your unit?

R.E. Schaffert: It is used to feed a biodigestor together with the bagasse. Excess stillage is applied directly as a biofertilizer.

J.N. Mushonga: Do people in Brazil chew sweet sorghum as in Zimbabwe and other southern African countries?

R.E. Schaffert: No, the sugar of sweet sorghum is used either for fermentation, or in a few cases in the Northeast, concentrated into a brick.

C. Wenman: How drought resistant are the sweet sorghum varieties?

R.E. Schaffert: Sweet sorghum, like all sorghums, is efficient in water use. However, when sweet sorghum is processed by extraction in the liquid phase it is necessary to have an adequate water supply.

P. Chigumira: How did you optimize the conditions in your counter current system prior to fermentation? Water addition would seem to have a diluting effect.

R. E. Schaffert: In the inclined horizontal diffusor, the water used in the counter current is recycled to enrich the sugars.

J.M. Chitsika: Is it possible for breeders to develop new sorghum varieties with higher starch content?

R.E. Schaffert: Yes. There is enough genetic variability in sorghum germplasm for desirable and required traits, such as high starch content. The breeders will have to start looking into this for utilization purposes.

P. Chigumira: Was the 95% recovery of extractable solids you reported achieved with a counter current extraction system?

R.E. Schaffert: The 95% that I referred to was the percent extraction of sugars in the biomass when an inclined horizontal diffusor is used to extract the sugars.

J.M. Mwale: How high is the distillation column?

R.E. Schaffert: In our case there are two columns, one on top of the other. The total height is about 10 m. Alternatively, the two columns could be placed side by side.

M.I. Gomez: Is the sugar content of sweet sorghum grain high or normal? Also, since local chewing sorghums appear to contain gummy exudates, do polysaccharides such as dextrans affect the sugar extractability?

R.E. Schaffert: The sugar and starch of the grain is the same as in any other sorghum grain. I have not encountered a gummy exudate in our sweet sorghums.

J.M. Chitsika: Is it possible for breeders to produce sorghum varieties with a much higher starch content than currently available?

R.E. Schaffert: I believe that it would be very difficult to greatly alter the starch content of sorghum grain. There appears to be a varying amount of starch in the stems of sweet sorghum.

Processing of Sorghum in Botswana for Foods and Feeds: Problems and Opportunities

N.F. Nicholson[1]

Abstract

Botswana is a semi-arid subtropical country, with low and highly variable rainfall. Production of maize and sorghum is insufficient to meet the demands of a growing population. Consumption of sorghum products is declining. There is an increasing trend toward maize and wheat products, which are more refined. This trend appears irreversible unless processing techniques are developed to produce more highly refined products from sorghum.

Introduction

Foods Botswana has been involved in the processing of sorghum in Botswana for foods and feeds since 1981. During that time Botswana has undergone 6 years of drought with a consequent decline in crop production and an increasing need to import food to sustain a growing population.

Geographical features of Botswana are as follows.

- Area: 582 000 km^2 of which almost two-thirds consists of the Kalahari Desert.
- Location: between 17° and 26° South. It is bisected by the Tropic of Capricorn and bounded by the Republic of South Africa, Namibia, Zambia, and Zimbabwe.
- Average altitude: 1000 m.
- Climate: subtropical with rainfall varying from 200 to 600 mm a^{-1}.
- Vegetation: a large part of the country, characterized by savannah vegetation, soft sands, and flat topography, is suitable only for livestock production and not arable farming. Livestock production is a major national industry and a large contributor to export earnings.
- Crop production: due to erratic rainfall total crop production has not exceeded 20 000 t a^{-1} since 1982. The crops produced are sorghum, maize, millet, beans/pulses, sunflower, and groundnuts. The majority of the cultivated land consists of small holdings which are farmed traditionally and yield less than 400 kg ha^{-1} maize or sorghum. Large-scale commercial farming has recently been introduced in certain areas, notably Pandamatenga on the northern border with Zimbabwe. It is too early to determine the long-term effects on crop production from these areas. However, a major problem with sorghum grown over these large areas is damage from birds.
- Population: currently estimated at 1.2 million. With the high growth rate of 3.4% a^{-1}, the population is forecast at 2.4 million by 2010.
- Cereal consumption: estimated at 210 000 t with sorghum at 60 000 t and millet at 2000 t. The balance (148 000 t) consists of maize, wheat, and rice. Maize and wheat consumption is increasing annually at the expense of sorghum and millet.

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Processing of Sorghum for Foods and Feeds

Present position

Existing human food products utilizing sorghum (with their Setswana names) are soft porridge (*motogo*) (sometimes fermented), stiff porriuge (*bogobe*), malt (*momelo*), and beer (*bojalwa*). Sorghum is also used as feed for cattle, pigs, and poultry.

Of the 60 000 t of sorghum consumed annually, 30 000 are sold commercially by the Botswana Agricultural Board to wholesalers, retailers, and millers. The remaining 30 000 t consists both of sorghum consumed directly by the producer and sorghum donated by aid organizations.

Two commercial maltsters and 10 operating commercial mills consume a total of approximately 15 000 t of sorghum per annum. The commercial mills are mostly small-scale enterprises employing less than 20 people. They use a horizontal abrasive dehuller designed by RIIC Kanye in cooperation with the International Development Research Centre of Canada. These machines work well with high-quality sorghum but have severe limitations with poor-quality sorghum.

Problems

1. ***Shortage of suitable quality sorghum.*** Because Botswana grows insufficient sorghum to meet its needs, it must import the crop from neighboring countries, particularly South Africa, which grows about 600 000 t ha^{-1}. South Africa's sorghum, which is grown primarily for malting or feed, is graded GM (suitable for malting), GL (low-tannin sorghum), and GH (high-tannin sorghum). Botswana imports all these grades—GM and GL for food and GH for feed. Grades GM and GL are sorghums with red pericarp and intermediate endosperm texture. They contain up to 5% kernels with a pigmented testa. These sorghums do not produce the preferred white flour.

2. ***No comparative cost advantage.*** In Botswana there are no consumer subsidies on food. Sorghum, however, carries a controlled price set by Government regardless of source. This price is considerably higher than the price of imported maize which is not controlled. As a result, sorghum meal is more expensive than maize meal. In addition, without the advantage of the relatively inexpensive high-tannin sorghum grown in South Africa, it is difficult to produce feeds that can compete with imports.

3. ***Poor marketing for byproducts.*** The byproducts of wheat and maize milling are readily disposable at realistic prices. Unfortunately, sorghum bran is considered nutritionally inferior. As a result it can be sold only at considerably lower costs than maize and wheat offal. This affects the profitability of sorghum milling.

4. ***Competition from maize and wheat products.*** The trend in recent years in southern Africa has been away from sorghum consumption towards consumption of maize and wheat products, which are considered more refined foods. With increasing urbanization, this trend appears irreversible. Botswana imports large quantities of refined white maize meal from South Africa and Zimbabwe. Unless sorghum can be processed economically to produce a white flour it will never compete adequately against maize meal, which is also cheaper.

Opportunities

The picture appears gloomy. Fortunately, there are market opportunities that have not yet been developed. These are as follows.

1. ***Production of a more highly refined flour.*** This includes enriching the sorghum flour with a vitamin mixture to give a product comparable to the vitamin-enriched maize meal sold commercially.

2. ***Production of pearled sorghum.*** This traditional Botswanan food, *mosuthane*, which can be cooked like rice, can be marketed at half the cost of rice.

3. ***Commercial brewing.*** Malt for home brewing is currently being produced only by the traditional open-floor method. Foods Botswana will shortly commission an indoor malting plant to produce high-quality malt. A feature of this plant is a conical steep tank with a 70-t capacity to be used for formaldehyde treatment of high-tannin sorghum.

4. ***Infant food production.*** Large quantities of Instant Corn-Soya-Milk (ICSM) are currently imported into Botswana. This product is distributed through Government Health Clinics to mothers and infants. Foods Botswana is investigating a mixture of dehulled sorghum and dehulled full-fat sunflower

cooked in an extruder with sorghum malt to reduce the viscosity and supplemented with vitamins and minerals. Considerable progress has recently been made in Pretoria on dehulling sunflower to produce a low-fiber food product. Sunflower is the main oil crop in southern Africa.

5. Composite flour production for traditional doughnuts. Wheat flour, which is not subsidized in Botswana and is therefore considerably more expensive than sorghum flour, can be mixed with sorghum flour to make a premix for *matemekwane*, a traditional doughnut. Recent investigations indicate that white bread flour sold in Botswana in 5-kg packs are popular for making *matemekwane*.

6. Feed. There is scope for increased utilization of sorghum bran and chemically treated high-tannin sorghum in feeds.

Conclusions/Recommendations

Production of sorghum in SADCC countries is being actively encouraged with the emphasis on end-product breeding. Increasing the output of sorghum will be counterproductive, however, unless the price of sorghum is competitive with maize and processing techniques are developed to produce more highly refined products. Information on the following topics would be of considerable assistance.

1. Millability tests

Sorghum milling should be tested in a laboratory. Standardization of a method for such testing should be agreed upon.

2. Sorghum tannins

Considerable confusion exists concerning the tannin content of sorghum. Evidence of this can be seen from the recent reclassification of South African sorghum into high- and low-tannin content. It is my understanding from publications of Dr Rooney and others that there is no such thing as a low-tannin sorghum; the only sorghums with tannin are those with pigmented testa and these are the high-tannin sorghums. A standard method should therefore be developed to measure tannin content.

3. Composite flours

Bread improvers in composite flours with a mixture of up to 50% sorghum flour should be developed.

4. Nutritional evaluation of sorghum bran

In vivo testing with ruminants or poultry should be undertaken to determine metabolizable energy. With increasing amounts of sorghum bran available from increased refining, there is an urgent need to determine the proper nutritional value so that the bran is realistically valued.

Discussion

M.I. Gomez: Are there any specifications concerning the GL and GH sorghum grades of South Africa in terms of actual tannin content, i.e., in catechin equivalent?

N.F. Nicholson: I am not aware of the detailed specifications. I would like a clarification of low- and high-tannin sorghum. Are there low- and high-tannin grains or high- and no-tannin grains?

L. Rooney: If there is no pigmented testa, there is no tannin.

N.F. Nicholson: What would be the minimum level for a high-tannin type?

L. Rooney: If there is a pigmented testa, tannins are present and catechin tests are required.

Potential and Actual Uses of Grain Sorghum in Foods and Related Research in Mexico

S. Bedolla[1], S.O. Serna-Saldivar[2], and L.W. Rooney[3]

Abstract

The paper presents an overview of the current uses of sorghum in Mexico and suggests potentially useful alternatives for the future. Included are descriptions of studies on dry milling and the preparation and cooking of tortillas.

Dry Milling Studies

Abrasive mills with auxiliary equipment are preferred for decorticating sorghum because the pericarp layers can be successively removed with some degree of control. For many food uses, red sorghum must be decorticated to reduce phenolics which often impair the acceptability of food products. The idea is to remove the pericarp without excessive loss of endosperm and nutrients.

In Mexico, several companies dry mill sorghum into products used by the brewing industry. Sorghum grits are used as adjuncts for beer production in Mexico. Dry milling involves decortication, impaction, and separation. The process yields 50% or more grits. Sorghum dry-milled products could be used for a wide variety of food and industrial products in Mexico because sorghum is usually less expensive than maize.

We designed an abrasive mill and evaluated its performance in decorticating two sorghum varieties. Figure 1 is a drawing of the Sonora Mill named MGS-1. The design was adapted from that of the PRL/RIIC abrasive mill developed in Canada by Reichert et al. (1984). The MSG-1 mill differed from the PRL/RIIC mill in the following aspects:

1. its capacity was 60 kg h^{-1};
2. it had a milling chamber of 10 kg;
3. it had 12 removable resinoid discs that could be set at different distances;
4. the outer discs were angled at 5° to improve mixing of the grain in the chamber;
5. a 7.5 hp, 220 volt, 3 phase, 1750 rpm motor with a 10-inch diameter pulley was used to rotate the discs at 2000 rpm; and
6. a volumetric feeder was adapted with a manually controlled feed regulator.

A white (NKX 8145) and a red (NKX 2775) sorghum were dry milled using an abrasive mill and then evaluated subjectively and objectively. White sorghum had a higher 100-kernel mass and was harder than the red sorghum type (Table 1). The

Table 1. Physical characteristics of sorghum hybrids dry milled in the MGS-1 abrasive mill.

Hybrid	100 kernel mass (g)	Grain shape[1]	Endosperm texture[2]	Color[3]
Red NK 2775	26.8	3	4	13.5
White NKX 8145	29.3	3	3	18.1

1. Completely spherical = 1; flat = 5.
2. Completely floury = 5; completely coreous = 1.
3. Higher values correspond with lighter colors (Agtron colorimeter). Measurements were made in the green mode using the 0% and 90% disk standards.

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Bedolla, S., Serna-Saldivar, S.O., and Rooney, L.W. 1992. Potential and actual uses of grain sorghum in foods and related research in Mexico. Pages 103-112 *in* Utilization of sorghum and millets (Gomez, M.I., House, L.R., Rooney, L.W., and Dendy, D.A.V., eds.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

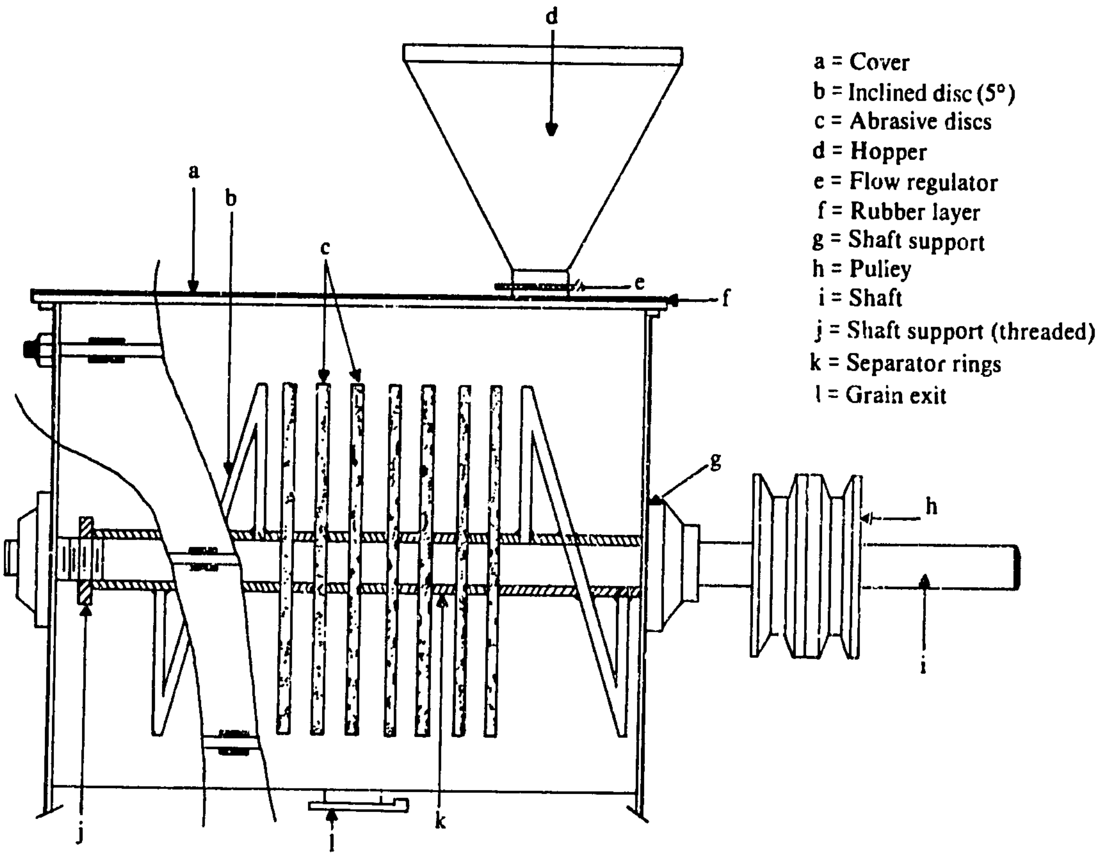

Figure 1. Drawing of the MSG-1 Mill developed at University of Sonora, Mexico.

kernel shapes were similar. As expected, the white sorghum had a lighter color (Agtron colorimeter) than the red sorghum.

Table 2 shows the effect of number of discs and grain residence time on the grit recovery index for red and white sorghums. In general, an increase in the number of discs resulted in greater decortication independent of both sample size and grain residence time. However, increasing the number of discs lowered the grit recovery because more broken kernels were produced. In Mexico, a good quality grit is one that stays on a US no. 10-12 Tyler screen, has quasi-spherical shape, and has approximately 70% of the pericarp removed (Cisneros 1984).

For white sorghum the grit recovery index was substantially higher, indicating that sorghum with hard endosperm produces high yields of commercial grits (US 10 and 12) with less breakage and more pericarp removed. The optimal conditions for mill operation were: mill holding capacity = 8-10 kg and number of discs = 8 with a variable residence time to reach the specified standards of pericarp removal.

The grit recovery index indicated that the recovery for red sorghum approached commercial standards. However, grit recovery for the white sorghum averaged more than that of red sorghum. These results suggested that the new abrasive mill could be used in rural and urban plants to produce decorticated sorghum products which could be used as raw materials for the elaboration of foods via nixtamalization, extrusion cooking, or other processes.

The relationship between grain residence time and amount of weight removed (Fig. 2) and grain residence time and amount of grits recovered (Fig. 3) after dry milling 10 kg of white and red sorghum samples with 8 discs was linear. The amount of mass removed from white sorghum was always significantly lower due to its harder endosperm texture. The gap between the two sorghums was wider as the residence time approached 3 min. For instance, at 3 min residence time, the recovery of grits from white sorghum was 74% versus 45% for red sorghum. In contrast, at a residence time of 5 min, the recovery for red sorghum was only 29% (unacceptable for commercial purposes) and for white sorghum 62%. Therefore, the proper handling of the operating conditions in the MSG-1 mill could lead to more efficient utilization of sorghum. The abrasive mill, along with other milling procedures, should produce an array of products with different specifications that could be used in many different human foods. For example, this mill was used to decorticate sorghum for tortilla production.

Table 2. Effect of number of abrasive discs and sample size on commercial grit recovery index (CGRI)[1] of red (NK 2775) and white (NKX 8145) sorghums milled for 1 and 5 min.

Residence time (min)	Sample size (kg)	Number of discs 8	10	12
		Red sorghum		
1	1	84	78	78
5		49	45	45
1	6	87	85	79
5		57	55	48
1	10	86	82	76
5	61	58	40	
		White sorghum		
1	1	90	88	90
5		67	62	60
1	6	94	90	93
5		75	65	72
1	10	92	89	91
5		77	66	74

$$1.\ \mathrm{CGRI} = \frac{\text{Mass on US no. 10 + US no. 12}}{\text{Original mass}} \times 100$$

Recent dry milling studies with the same sorghum types were conducted to study differences in milling behavior between sorghums tempered at different moisture levels. Tempering reduced the amount of broken kernels and produced better grits. An interaction between sample size and moisture content was found to affect grit recovery indices. Details of the study will be published shortly.

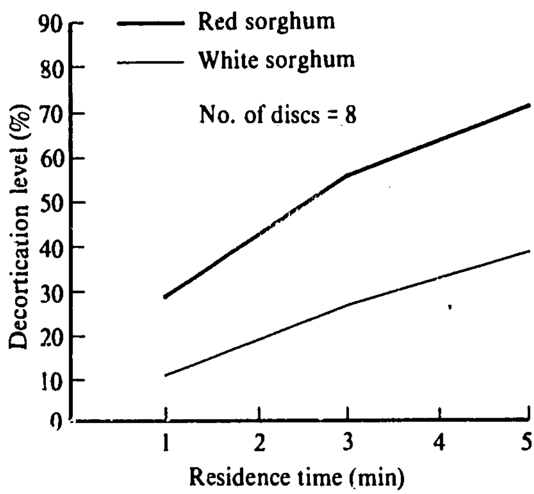

Figure 2. Relationship between grain residence time and decortication level for white and red sorghum using the MSG-1 Mill.

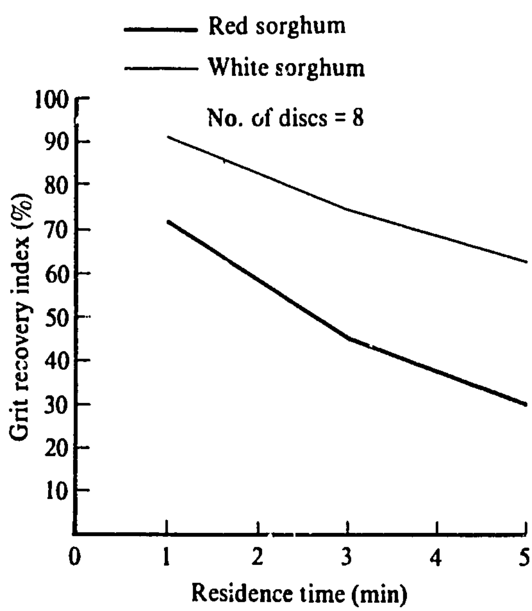

Figure 3. Relationship between commercial grit recovering index and grain residence time of white and red sorghum using the MSG-1 abrasive mill.

Cooking Procedures for Sorghum Tortillas in Commercial Plants

Maize, in the form of tortillas, provides most of the calories, proteins, and calcium in Mexico, Guatemala, and Honduras (Trejo-Gonzalez et al. 1982). The per capita consumption of maize in Mexico is estimated at 130 kg per year. For various reasons, maize hybrids and varieties in Mexico are not well adapted and are relatively unproductive. On the other hand, sorghum hybrids with outstanding yield and agronomic properties are commercially available. For this reason sorghum is now the second largest cereal crop after maize.

Average sorghum yields in Mexico are significantly greater than those for maize, and sorghum is more drought resistant. It has been established that sorghum and maize have similar chemical composition and nutritional values, although sorghum contains undesirable phenolic compounds from a processing standpoint (Rooney et al. 1980, Bedolla and Rooney 1982, Bedolla et al. 1983, Serna-Saldivar 1984). Research conducted in recent years indicates that sorghum tortillas of acceptable color, texture, and flaver can be produced when sorghum is optimally processed (Khan et al. 1980, Bedolla et al. 1983, Bringas and Rozaud 1985, Choto et al. 1985, Bedolla 1983). Most of this data, however, has been generated on a laboratory scale and data on a commercial basis are needed to accurately assess the use of sorghum for tortillas. This paper reports our experience in utilization of sorghum for tortillas in the pilot plant at the University of Sonora and in commercial tortilla plants located in Hermosillo. It summarizes experiments on sorghum processing using equipment and procedures used in cooking, forming, and baking maize tortillas.

Commercial cooking procedures in Sonora

An exhaustive review of the steps involved in processing maize tortillas was made in two tortilla plants in Hermosillo before the project was started. In one factory, the maize contained both white and yellow kernels (30:70). Maize was often mixed with sticks, soil, stems, rocks, and other impurities, thus requiring scalping and sieving operations. Scalped maize was placed in a 600-kg capacity cooker containing 2000 L hot water (93°) and 9 kg calcium oxide. A wooden paddle was used to turn the mass of grain and a wire screen removed the floating impurities. When the grain was added to the cooker, the temperature dropped to 81°C and remained stable for almost 40 min. It started to decrease at this point. The grain was steeped for approximately 18 h at pH 12. The cooking and steeped waters were decanted, grain was washed with water (approximately 1.5 volumes), and lime-cooked grain was stone-milled to masa. Approximately 60 mL water per 1 kg of nixtamal were added while stone milling. Twenty-five kg nixtamal was stone-milled and the masa obtained was kneaded for 3 min in a horizontal mixer. Masa was sheeted, formed by rollers, and baked into tortillas in a triple-pass gas-fired oven. Tortillas were baked at 250°C for 1 min (Table 3).

Table 3. Optimum cooking times determined experimentally for sorghum (white, X 8145) and maize (white, T250-F)—20-kg lots using a 600-kg capacity cooker in a commercial tortilla plant.

	Cooking/ holding time (min)	Steep time (min)	CaO (%)	Cooking temp range (°C)
Sorghum	20	600	0.8	82-84
Maize	35	1200	1.5	82-84
Decorticated sorghum				
6%	12	15	0.8	82-84
10%	8	15	0.8	82-84
18%	5	15	0.8	82-84
Commercial maize[1]	0	960	1.5	93-28

1. Cooking procedures used in commercial tortilla plants at Hermosillo, Sonora, Mexico.

Cooking procedures at the University of Sonora Pilot Plant

Whole sorghum and maize. Water and calcium oxide (maize 1.5%, sorghum 0.8%—on grain mass basis) were brought to 93°C in a 50-kg capacity gas-fired cooker. Grain: water ratio was 1:3. Lots of 35 kg were processed. Upon addition of grain to the cooker, the temperature dropped from 93°C to 83°C in approximately 5 min. Therefore, the cooking range was 83-89°C. After 20 min, the heat was turned off and the sorghum was steeped for 10 h. Maize was cooked for 35 min using the same procedure, but steeping time was 16 h. After steeping, the nixtamal (cooked grain) was transferred to a 50-kg capacity steep tank and washed with 40 L water with a hose.

The washed nixtamal was then stone-milled (12-inch volcanic stones) and masa was formed into tortillas in a Celorio tortilla machine (which mixes, extrudes, and forms the masa into tortillas) and baked in a triple-pass oven.

Decorticated sorghum. For decorticated sorghum (6%, 10%, and 18% mass removed), either white or red, the cooking procedure resembled that for whole sorghum and maize, but optimal cooking times were 12 min for the 6% decorticated grain, 8 min for the 10% decorticated grain, and 5 min for the 18% decorticated grain. The cooking temperature was 82-86°C and the concentration of CaO was 0.8% for decorticated samples. After attaining the optimal cooking time for each sample, the heat was turned off and the grain was steeped for 15-20 min. Then the grain was washed, stone-milled, and formed into tortillas as described for whole sorghum and maize.

Sorghum/maize mixtures. Sorghum (either whole or decorticated) and maize were cooked separately and the following mixtures formulated: whole white sorghum and white or yellow maize (25:75, 50:50, and 75:25); for decorticated white sorghum and white of yellow maize (50:50 and 75:25); and for decorticated red sorghum and white or yellow maize (50:50). The mixtures were blended in a horizontal mixer for 5 min and stone-ground. The forming and baking were as described previously.

Two white sorghum hybrids (ATX 623 × CS 3541 and Northrup King × 8145 NK) and two red hybrids (ATX 378 × TX 430 and 2775 NK-PN) were processed to find the optimal cooking and milling conditions. Three levels of decortication for white sorghum (6%, 10%, 18%) and one level (18%) for red sorghum were tested. The controls were maize tortillas produced from white maize (Northrup King T250-F) and yellow maize (Northrup King T-66).

Preliminary cooking trials. Based on the commercial cooking procedure outlined for maize, one experiment was planned for white sorghum where steep time, CaO concentration, and sample size were the independent variables. Increasing the steep time from 10 to 16 h produced sorghum nixtamal and tortillas comparable to corn tortillas. However, the color of sorghum tortillas was not acceptable, indicating that the level of CaO should be reduced. More data is needed on the effects of CaO concentration and steep time on flavor development for different white and yellow sorghums. A decrease in the CaO concentration produced a nonsticky masa, particularly at 0.8% CaO level and improved the color of tortillas. The flavor of sorghum tortillas is not as strong as the flavor of maize tortillas.

Studies at the University of Sonora Pilot Plant

Pilot plant studies indicated that when processing small lots of grain (20 kg), higher temperatures should be used to compensate for the faster heat losses. In commercial operations where 600-kg batches are usually cooked, heat was lost at a slower rate, thus considerably decreasing energy expenditure.

In general, sorghum grain required only 57% of the cooking and steeping time of white maize and 50% of that for yellow maize. Decorticated sorghum required only 23% of the cooking and steeping time of white maize, and 1.2% of that for yellow maize. Therefore, processing sorghum into tortillas in a commercial plant can reduce energy costs considerably.

Table 4 shows a set of cooking experiments conducted at the pilot plant at University of Sonora. The optimal cooking times determined in the commercial tortilla plant were used to process sorghum, maize,

Table 4. Parameters used during cooking of maize, sorghum, and maize/sorghum blends in a pilot plant at the University of Sonora.

Treatment	Cooking/ holding time	Steep time (h)	CaO (%)	Cooking temp. range (° C)
I. WS (X 8145)	20	10	0.8	75-88
II. WS (X 8145)	30	10	0.8	75-88
III. WM (method 4)	35	16	1.5	93-28
IV. 50% WS/50% WM (sorghum and maize were cooked separately before making the mixtures)				
V. 75% WS/25% WM				

WS = White sorghum from Treatment I.
WM = white maize.

and two sorghum/maize mixtures. Table 5 displays the yields of nixtamal, masa, and tortillas; water added during stone-milling; and milling time. Sorghum nixtamal yield at 20 or 30 min cooking time was higher than that for maize.

However, tortilla yield for the sorghum cooked for 20 minutes was similar to that for maize. This was because maize nixtamal required more water at the milling stage. Sorghum cooked for 30 min produced a sticky masa difficult to sheet but had a high tortilla yield. Tortillas from overcooked sticky masa had poor texture. The 50:50 and 75:25 sorghum/maize mixtures gave excellent masa and rollable tortillas after 48 h, indicating that 20 min was an optimal cooking time for sorghum. Tortillas from the 50:50 mixtu had an acceptable color, whereas those from tl 75:25 mixture did not. In addition, it suggested th mixing optimally cooked sorghum and maize f cilitated the use of sorghum in tortillas.

Moisture content of sorghum nixtamal was signif cantly higher than that for maize or any sorghun maize blend (Table 6). Moisture content of masa fo each of the treatments shown was an indication of th water requirements during stone milling. Maize toı tillas had less moisture than sorghum tortillas, thu indicating a further reaction between the phenols an CaO during the baking process (Table 6). Darker toı tillas resulted from either sorghum or any sorghun

Table 5. Properties measured during the alkaline processing of sorghum, maize, and, sorghum/maize mixtures in a pilo plant.

Treatment	Cooking time	Nixtamal yield (kg kg^{-1} grain)	Masa (kg kg^{-1} grain)	Tortilla yield (kg kg^{-1} grain)	Milling rate (kg min^{-1})	Water added to nixtamal at mill (mL kg^{-1})
I. WS (X 8145) 20 min cooking	20	1.82	1.83	1.40	3.6	127
II. WS (X 8145) 30 min cooking	30	1.94	2.07	1.75	1.4	241
III. WM	35	1.46	2.61	1.33	1.8	260
IV. 50% WS/50% WM	mixture	–	–	1.24	3.9	206
V. 75% WS/25% WM	mixture	–	–	1.31	4.2	133

WS = white sorghum X 8145 from Treatment I; WM = white maize.
Note: The size of the starting sample was 20 kg of grain.

Table 6. Moisture, color, water absorption index, stickiness, and rollability of tortilla produced from white sorghum (X 8145), white maize (T250-F), and their blends.

Treatment	Moisture			Degree of masa stickiness (subjective)	Tortilla			
					Color[1]		Rollability[2]	
	Nixtamal	Masa	Tortilla		0 h	24 h	0 h	24 h
I. WS (20 min cooking)	49.2	56.2	45.0	Low	30.5	29.0	1	2
II. WS (30 min cooking)	54.3	59.8	46.4	High	27.6	26.6	4	5
III. WM	42.3	56.2	38.5	Low	47.4	47.0	2	3
IV. 50% WS/50% WM	46.7	55.0	41.3	Very low	39.0	38.2	1	2
V. 75% WS/25% WM	47.5	54.6	40.8	Very low	35.0	34.1	1	2

1. Measured with an Agtron colorimeter using the green mode.
2. Subjective rollability where 1 = highly rollable with no cracks; 5 = nonrollable, high breakage.
3. WS = white sorghum; WM = white maize.

maize mixture in comparison with lighter color tortillas from maize. Maize tortillas did not change color during 24-h storage. On the contrary, any tortilla that contained sorghum underwent a color change after 24-h storage. These studies confirmed that white sorghums with tan plant color are ideal for tortilla manufacturing and that purple or red plant color is undesirable.

Technological solutions to improve sorghum tortilla color include the development of white genotypes with tan glumes and tan plant color, the use of sorghum/maize mixtures, and the use of abrasive dry milling to partially remove the pericarp where most of the phenols are located. The effect of weathering on sorghum quality for tortillas is especially significant because weathering enhances content of phenolics which cause dark undesirable tortillas.

The water absorption index of dry masa did not correlate with the moisture content of nixtamal for the treatments shown (Table 6). Perhaps drying the masa caused unknown changes in the major chemical components. Sticky masa could not be handled by the tortilla machine; such tortillas had poor flexibility after baking and storage for 24 h. The rest of the treatments containing sorghum resulted in more rollable tortillas than the maize control, probably because of the higher moisture content of the sorghum masa.

The protein content of sorghum tortillas was higher than that of maize tortillas and similar to that of tortillas from either blend (Table 7). This was because more maize protein was lost during cooking and soaking. However, lipid content of maize tortillas was higher than that of sorghum tortillas or any sorghum/maize blend.

Tortillas from decorticated sorghum and decorticated sorghum/maize mixtures

Decorticated (10% weight removed) white sorghum ATX 623 × CS 3541 from the Texas INTSORMIL Program produced whiter, more rollable, and more flavorful tortillas than the two white sorghums used previously. The cooking conditions were as follows: CaO = 0.8%; water:grain ratio = 2.5:1; cooking time = 8-10 min at 84°C; and 15 min steep time. The only problem observed was the rapid staling rate (hard texture formation) exhibited after baking the tortillas. This may be associated with the amount of pericarp present in the kernel, particle size of the masa, or the reduced level of fat in decorticated sorghum.

Sorghum (ATX 623 × CS 3541) could replace approximately 50% maize (white or yellow) without any textural or color problems. When decorticated to remove 18% of the grain weight, this sorghum could replace about 75% of either maize.

Decorticated white sorghum with purple plant color, Z 8145, when abrasively milled to remove 6% of the original weight, could replace 20% of white or yellow maize. When milled to remove 10% of the weight, it could replace 30% of maize, and if milled to 18% could replace fully 50% of maize. Decorticated red sorghum (18% weight removed, ATX 378 × TX 430) could replace a maximum of 40% white or yellow maize. Tortillas from decorticated red sorghum (18%), in combination with any type of maize, would be very acceptable in southern Mexico. Northern Mexican consumers prefer white or slightly cream-colored tortillas such as those from the white sorghum (ATX 623 × CS 3541), but in many areas tortillas with a dirty brown color are commonly used because of the importation of poor quality yellow maize. Sorghum could in fact improve the color of

Table 7. Chemical composition of tortillas from grain sorghum, maize, and their mixtures processed in a pilot plant at the University of Sonora.

Treatment	Protein (N × 6.2) (%)	Lipids (%)	Ash (%)	Moisture content (%)
I. WS (X 8145) 20 min cooking	11.1 (11.4)[1]	3.5 (4.1)	1.9 (1.6)	46.0
III. White maize (T250F)	9.4 (11.9)	4.8 (5.2)	1.6 (1.3)	39.0
IV. 50% WS/50% WM	10.1	4.0	1.7	42.0
V. 75% WS/25% WM	10.6	3.9	1.8	40.8

Numbers in parentheses are values for the original grain, either sorghum or maize.
WS = white sorghum X 8145 from Treatment I.
WM = white maize from Treatment II.

those maize tortillas significantly. ATX 623 × CS 3541 has a red plant color, but because the grain was not subjected to weathering and molding it had good tortilla-making properties.

General Comments Concerning Sorghum for Tortillas

Tortillas have been produced in pilot and commercial plants from whole sorghum grain (either white or red), decorticated sorghum, and from sorghum/maize blends. In these experiments, sorghum masa was formed into tortillas using sheeter with rollers and with an extrusion mechanism (Celorio brand). These are the two principal types of machines used in Mexican tortilla factories. Maize processing equipment could be used for sorghum. Any operator could easily adjust to the reduced cooking and steeping times required for sorghum.

Quality of sorghum tortillas could be improved in three ways. First, sorghum could be cooked in the waters used for maize after completion of its steeping period. The resulting liquors would be more concentrated and the solids could be easily recovered, thus avoiding pollution. Sorghum tortillas would thus be more flavorful. Second, sorghum could be added right after the end of the cooking period of maize when the temperature is about 84°C. Sorghum would be partially cooked, thus avoiding drastic off-color reactions and improving the flavor. Third, white decorticated sorghum could be blended with red decorticated sorghums and then cooked as previously described to produce acceptable tortillas from sorghum grain.

The most significant problem may be the stickiness that occurs when sorghum is overcooked; this may happen after 2-4 min. Overcooking and/or inappropriate stone milling could lead to loss in tortilla texture and a rapid rate of staling. These problems are related to the particle size of masa and to the starch gelatinization. Stickiness, however, can be overcome by mixing sticky masa with an optimally cooked maize masa and letting it rest for approximately 25 min or by using dry masa flour. The Celorio tortilla-forming machine is widely used in Mexico. It requires an accurate range of particle sizes and moisture content for masa; otherwise, the machine will not form tortillas. Sorghum masa was extruded efficiently. Tortillas formed with the sheeter using rollers do not puff as those made in the Celorio. Puffing is an important quality parameter for table tortilla customers.

These studies indicated that sorghum can be used alone or in mixtures with maize for tortilla production. Sorghum requires reduced cooking and steeping time and lower levels of alkali. Sorghum alone has a bland flavor. A white sorghum with purple plant color produced significantly off-colored tortillas. Decortication of the grain to remove the pericarp reduced cooking and steep times and improved the color of the tortillas significantly.

Development of Precooked Tortilla Flour with Low-Cost Extrusion Cooking

The feasibility of using traditional extrusion cooking technology to produce shelf-stable instant tortilla flour has been documented previously (Bedolla 1983, Almeida-Dominguez 1984, Bazua et al. 1979) but no studies have been documented using low-cost extrusion cooking (LCEC). The LCEC technology has several advantages:

- instant flour could be produced in a continuous process;
- water and dry matter losses are eliminated;
- grain does not require cooking and steep time;
- drying costs are considerably diminished; and
- the equipment requires reduced space and labor.

Serna-Saldivar et al. (1988) reported that instant tortilla flours could be easily fortified with oilseed flours when produced by extrusion cooking. The nutritional value of maize/sorghum tortilla mixtures fortified with defatted soybean meal was considerably better than the unfortified system.

The objective of the study summarized here was to develop the technology to reproduce nixtamalized sorghum/maize flours with the use of LCEC.

A pilot plant equipped with a Brady ECH-600 low extruder and auxiliary equipment was used. The plant is located in Chihuahua, Mexico.

Based on preliminary cooking trials, an experimental procedure for the production of instant tortilla flour was optimized (Fig. 4). Proximate analyses, pH, color, water absorption index, enzyme susceptible starch (an index of starch gelatinization), particle size distribution, and viscosity were determined (AACC 1976, Bedolla 1983). The dry masa flours were processed into tortillas and tested with the Universal Instron Testing Machine and by a sensory evaluation panel. Low-cost extrusion technology showed potential to produce maize/sorghum dry masa tortilla flours. Based on the quality of the parameters selected, a mixture of 75% maize and 25% decorticated sorghum (18% mass removed) produced tortillas similar to those made with the most popular dry masa

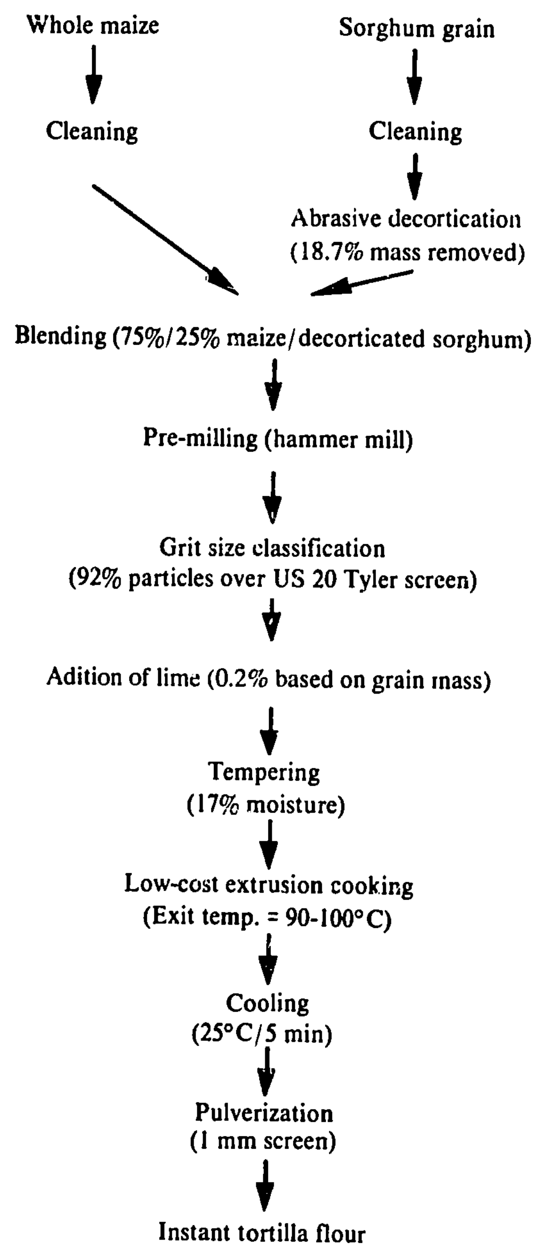

Figure 4. Experimental procedure for the production of maize/sorghum dry masa flour via low-cost extrusion.

flour. The optimum cooking conditions were: (1) a coarse grit (93% over US no. 20 sieve); (2) grits conditioned at 17% moisture with 0.2% lime; and (3) an extruder temperature of 100°C. The particle size distribution, extrusion temperature, and grit moisture content significantly affected dough viscosity, flour and tortilla color, and water absorption. These properties could be used as the main quality parameters for the optimization of the process. The main problem during processing was to reach the steady state of equilibrium of the grain flow through the extruder barrel. This could be controlled by the selection of a correct grit size and by a columetric feeder.

Low-cost extrusion requires considerable power and the abrasive sorghum grits wear out the extruder quite rapidly. Although our data indicates the process may be useful, more information on consistency of the products, operating costs, and cost of maintenance are required.

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Industrial Uses

Industrial Uses of Sorghum in Nigeria

J.S.T. Bogunjoko[1]

Abstract

Cadbury Nigeria Limited, Ikeja, has pioneered the industrial use of sorghum in Nigeria, and this paper discusses our experience and the present state of sorghum usage by Nigerian industries. The changing economic prosperity of Nigeria, indicated by the massive devaluation of the Naira over the past 8 years, meant that the cost to the industry of malted barley has varied from N 300 (US$ 480)t^{-1} in 1980 to N 2800 (US$ 620)t^{-1} in 1987, before a ban was introduced on the import of malted barley. Glucose syrup also varied from about N 300 (US$ 480)t^{-1} in 1980 to the present cost of N 3900 (US$ 870)t^{-1}. On the other hand, the price of sorghum has varied from N 200 (US$ 260)t^{-1} in 1983 to the present cost of N 800 (US$ 180)t^{-1}. These price variations have brought the industrial use of sorghum by the beer and food industries into prominence in Nigeria. Added to this scenario is the fact that, by and large, agricultural production is once again on the increase and the question is raised as to what happens to this increased output of grains.

Background and Introduction

In the past 5 years, sorghum usage by Nigerian manufacturing industries has gone from zero to the current estimate of about 20 000 t per annum with an anticipated increase of 2–300 000 t per annum in the next few years. This follows the announced ban on the importation of malted barley into the country as of 1 Jan 1988.

This paper relies heavily on the experience of Cadbury Nigeria Limited, a pioneer in the industrial utilization of sorghum in the country, and also on the current situation and future projection for other industrial users, especially the beer subgroup.

Cadbury Nigeria makes a malt/cocoa drink called Bournvita and has for the past 10 years been producing about 20 000 t malted barley per annum. The main difference between our work with sorghum and that of a brewery is that we evaporate the extracted wort into a syrup instead of fermenting it into a beer.

In the early 1980s, with the reduction in the price of crude oil, Nigeria's main foreign exchange earner, and the mismanagement of the economy, the government introduced tighter fiscal policy through the use of Import Licences for all imports. Since the average Nigerian still had a lot of Naira to spend, this restraint on the importation of raw materials by industry meant that a considerable amount of money was chasing few goods. Manufacturers were therefore unable to satisfy market demand because of the limited access to imported raw materials. This situation obliged many companies to explore new ways to extend their production capacities through the use of alternatives to malted barley.

What started as a means of increasing capacity progressively became a primary issue with the devaluation of the Naira and the price variation of both malted barley and glucose syrup between 1980 and 1988. As seen in Table 1, the Naira was continuously devaluated, climaxing in a foreign exchange auction arrangement known as the Foreign Exchange Market (FEM), where the rate was determined by an aggregate of the bidding prices.

This same period was also characterized by:

- increased unemployment rates (reduced purchasing power);
- wage freezes;
- price controls of manufactured items;
- increased attention by Government to agriculture as a means of solving unemployment problems and minimizing the importation bill;

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Bogunjoko, J.S.T. 1992. Industrial uses of sorghum in Nigeria. Pages 115–119 *in* Utilization of sorghum and millets (Gomez, M.I., House, L.R., Rooney, L.W., and Dendy, D.A.V., eds.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

- sluggishness by both medium and large companies in sourcing new raw materials while maintaining good corporate images; and
- comparative stability of the price of sorghum.

Table 1. Changes in factory price of malted barley and glucose, 1980-88.[1]

	Average cost t^{-1}	
Year	Malted barley	Glucose
1980	300	300
1981	310	300
1982	340	400
1983	400	500
1984	550	500
1985	1000	2000
1986	1900	2500
1987	2800	2800
1988	Banned	3900

1. All figures in Naira.

The Growth of Beer Production and Other Malt Exchange Usage in Nigeria

Malted barley for beer production

Nigerian Breweries Limited pioneered local manufacture of beer with their first brewery in 1948. By 1962, Guinness Nigeria Limited and Golden Guinea Breweries were also producing beer. North Brewery Kano started operating in 1970, and by 1983 31 breweries of varying capacities and brands were operating in Nigeria with a total installed capacity of about 8 million hL. The number of breweries has now increased to about 40 with a total installed capacity of 18 million hL capable of utilizing about 300 000 t of malted barley.

Malted barley/malt extract for food uses

Cadbury Nigeria accounts for half of an average annual usage of about 20 000 t malt extract by the food industry. Only Cadbury Nigeria, however, which maintains a malt extract plant with a capacity for sorghum adjunct usage, has embarked on projects leading towards the full-scale usage of sorghum/sorghum malt for malt extract equivalents and for glucose production.

Why sorghum?

For a number of years, research institutes in Nigeria have been working on sorghum breeding, multiplication, and popularization of improved varieties with the Institute for Agricultural Research (IAR) at Ahmadu Bello University in Zaria in the lead. The Federal Institute of Industrial Research, Oshodi (FIIRO) has also worked on the possible industrial application of sorghum in the areas of malting and syrup production.

IAR has introduced a number of improved sorghum varieties to Nigerian farmers with the aim of providing drought-tolerant, *Striga*-resistant varieties that produce higher yields than the traditional varieties. FIIRO recommended to the Government that sorghum varieties, especially SK 5912, could be malted and used as a substitute for malted barley in beer production. Industry took its cue from this report and initiated further research and development. Without waiting to install infrastructures for the utilization of raw sorghum or for the manufacture of malted sorghum, however, the Government banned the importation of malted barley.

Choice of sorghum varieties for processing

A number of factors affect the selection of a variety for processing apart from reasonable farm performance. These include:

- availability of pure varieties;
- percentage of available starch;
- level of protein and fat content;
- level of tannin/glucane content; and
- flavor development in the extract or wort during processing.

In addition to the above considerations, two other factors are important in selecting malting grain. These are germination capacity and diastatic power.

Because varietal purity has not been maintained by the farmers, most industrial processors have opted for the white *fara fara* or the creamy SK 5912. Cadbury Nigeria, however, began commercial-scale investigations of the properties of other varieties from seeds produced by IAR. Production of pure seeds by both Government research centers and private sector seed companies is necessary if industry is to obtain the best varieties for processing.

Sourcing of Sorghum for Industrial Use

Cadbury Nigeria's experience

When we were looking for industrial quantities of sorghum 5 years ago, we discovered that the Nigerian farmer referred to the different varieties of sorghum only as white, yellow, or red. For the short term, we went to the areas where IAR had conducted their field/farmer trials and applied a premium pricing policy. This meant that any grain merchant who could supply sorghum according to certain loose specifications got a 100 Naira t^{-1} premium above the market price.

Building on this concept, we bought seeds, distributed them to our contract farmers, and initiated the development of an outgrowers system. We also entered into agreement with a State Farmers Council with whom we could negotiate prices. The Council distributed the seeds to the farmers and performed preliminary quality checks of the grain. We discovered that through this system we had access to hundreds of farmers with improved seeds who practiced optimal farming techniques. We were then able to tighten our specifications in terms of moisture content of grain, purity of variety, foreign matter, and infestation level.

Sorghum pricing development

Our experience with sourcing sorghum indicates that its price is affected by two factors:

1. Government activities in promoting other crops within the sorghum-growing areas (such as groundnuts and cotton) in terms of heavily subsidized inputs into these other crops; and
2. the variation in such weather conditions as the droughts in 1984 and 1987.

It is estimated that the base price for sorghum will fluctuate between 1000 and 1200 Naira t^{-1} in 1989 and 1990 (Table 2). The demand created by industry is expected to popularize the cultivation of the favored, improved varieties like SK 5912, and to inculcate the practice of using pure seeds for pure grains to obtain premium quality.

Table 2. Sorghum price changes, 1983-88.[1]

Year	Price t^{-1}
1983	200
1984	500
1985	600
1986	700
1987	500
1988	800
1989/90 (Estimate)	1000-1200

1. All figures in Naira.

Projections for sorghum usage by industry

In order to estimate current utilization and future demand of sorghum, the following assumptions are made.

1. The total brewing capacity of 18 million hL will not be appreciably increased in the near future.
2. In 1987 there was an average of about 40% capacity utilization in the brewing industry. This is expected to increase to 50% by the end of 1989 when stocks of malted barley will be depleted.
3. The use of adjuncts will increase from present levels of about 30% to about 60% by the end of 1989.
4. About 70% of all adjuncts will soon be sorghum, 30% maize, and a small percentage of rice.
5. By the end of 1989 it is expected that several breweries will convert some of their facilities to handle 100% local raw materials. The overall capacity utilization, however, would remain about 50%.
6. Capacity utilization will gradually increase to 100% by 1995.
7. These estimates are based on the use of raw grains and enzymes as the use of malted sorghum on a large scale may not be possible within the next few years.
8. For these estimates, it is assumed that 1 t sorghum grain will produce 70 hL lager.
9. There will be a progressive increase in sorghum to 25 000 t per annum by 1995 for the use within the food industry.
10. If the development of the malting industry does take off, sorghum usage will increase by 30-50% of the estimates given from 1990 to 1995 (Table 3).

Table 3. Estimate of sorghum requirements by the brewing and food industry, 1989-95.

Year	Sorghum usage per annum by the brewing industry	Sorghum usage per annum by the food industry
1989	50 000 - 60 000	6 000 - 7 000
1990	90 000 - 100 000	15 000 - 17 000
1995	150 000 - 200 000	19 000 - 25 000

Equipment Requirements

A large percentage of breweries in Nigeria use the lauter tun to separate the wort from the mash. The lauter tun is an excellent piece of equipment for malted barley mashes. However, the higher the adjunct level, the more one gives away in throughput and wort clarity. With 50% adjunct, the throughput is already reduced by about 40%, and adjuncts above 70% make the lauter tun almost inoperable in normal production runs. The use of local grains, whether malted or unmalted, would require investment in new equipment. Filtration means and rates would then become the controlling factors in the production rate and the overall capacity of the industry. Achieving 1982/83 production levels depends on how the economy moves and how much investment is made. As can be seen from the process steps described in Table 4, an additional investment is required in milling, in gelatinization/cooling of mash, and in infiltration. For a medium-sized brewery, these changes may cost 20-30 million Naira.

Recommendations and Conclusions

Sourcing sorghum for industry

Considerable research effort is still needed into the breeding and propagation of improved varieties of seeds in order to increase the scope that industry has to choose from. Apart from farms owned by various companies as a result of their backward integration efforts, farmer cooperatives and agricultural development projects within the sorghum production zones can be used to provide the desired varieties. A deliberate government policy is necessary to meet this need and concerted efforts are required to popularize chosen varieties of sorghum.

Utilization of sorghum

The use of sorghum by the Nigerian manufacturing industry could grow from zero in 1983 to over 250 000 t in 1995, and to multiples of this quantity when additional investment in the local manufacture of glucose for the food and pharmaceutical industries can be obtained.

Equipment for processing

For most of the current users, additional investments in grain milling, conversion, and filtration are needed to be able to use 100% sorghum in normal production runs.

Table 4. Comparison of process stages and equipment requirements for processing malted barley and sorghum.

Process stage	Malted barley	Sorghum
1. Grain cleaning	Sieve system already installed	Same sieve system could be used with minor modification of sieve sizes
2. Milling	Usually wet milling using 2-roll mill	Dry milling required with hammer mill to attain desired granulometry
3. Gelatinization	No special gelatinization step required	Sorghum starch gels at a higher temp, dextrimizing enzyme may be used to soften the starch for enzyme attack by cooking at 90°C for 30 min
4. Cooling	No cooling step required	For optimal enzyme activity the gelled mash must be cooled to 50°C for optimum protease activity
5. Conversion	Mash vessel utilized	Conversion step required with low mixing
6. Filtration	Lauter tun	Mash filter press required

Enzyme requirement for processing

Enzyme requirements estimated at about 4 kg t^{-1} processed grain costing 500-600 Naira (at the present exchange rates of 4.5 Naira to 1 US dollar) would continue to be a major input and a foreign exchange drain. Sorghum malting will reduce this 60-70%. With the Government's assistance, industry must identify its investment in enzyme manufacture and/or sorghum maltings now in order to guarantee a secure future for the industry and to ensure the beneficial use of locally grown sorghum.

Discussion

S.Z. Mukuru: How does Bournvita prepared with sorghum malt compare with Bournvita prepared with barley malt with respect to quality and consumer acceptability?

J.S.T. Bogunjoko: The exogenous enzymes used, and processing stages, especially during evaporation of water, allows the amino acids and sucrose to develop flavor. This taste is similar to malt extract from barley. We see a need to add a small percentage of malted sorghum to increase the maltiness of the taste of the extract. The product thus produced gives a perfectly acceptable product with good consumer acceptability.

Industrial Utilization of Whole Crop Sorghum for Food and Industry

L. Hallgren, F. Rexen, P.B. Petersen, and L. Munck[1]

Abstract

The total utilization of the sorghum plant in a balanced production of food, feed, and selected industrial products will become increasingly important in the developing countries. The production of fibers from local cereals as sources of cellulose for paper, particle board, and chemicals for industry is suggested, with a view to reduce the need for import of these components. Experiences with separation and characterization of botanical components of straw from cereal species other than sorghum are outlined, and parallels are drawn to sorghum. The leaves of the plant can be used for livestock feed or as an energy source. Even the polyphenols from high-tannin varieties may be utilized for the production of glue for particle board production. Low-tannin sorghum grain is an important potential food source and the starch can be utilized as a raw material for the chemical industry. Industrial processes based on the principle of separating the kernel into components, which can be used for feed or fuel, or which have special food properties (for porridges, brewers' grits, flat breads, composite flour, biscuits, etc.), are suggested.

Introduction

Most developing countries produce cereals, which are traditionally used as food or feed. Cereal crops may also be used for production of a number of useful industrial products which are unavailable locally or must be imported. The sorghum plant is a potentially attractive raw material for feed, food, fuel, and industry. It can be separated in to a number of different kernel and straw fractions for industrial applications such as particle board, paper, adhesives, detergents, plastics, and sugars. Several of these items are presently unavailable in many developing sorghum-growing countries and must therefore be imported. A total utilization of all components in the sorghum plant (including the straw part) for use in the manufacturing and food industries would increase cash flow to the farmer and thereby constitute an incentive for him to increase his production. In a report for the European Economic Community (EEC), Carlsberg forecast a surplus of cereal grains in the EEC countries in 2000 of at least 58 million t of a total production of 186 million t (Rexen and Munck 1984). If oil prices are increased and maintained at higher levels than at present, part of this surplus could be absorbed into starch-based manufacturing industries. A massive surplus for export, however, is still likely. Although it is tempting to contemplate selling this surplus cheaply or even donating it as aid to developing countries in Africa, the dumping of EEC surplus on the world market would simultaneously become a nightmare to farmers in those countries. When sorghum and millet prices are undercut by low prices of imported wheat and maize, the farmer's incentive to produce for the cities is crippled. Compounding the problem is the lack of processing facilities for making sorghum and millet into convenient foods suitable for consumption by the urban population, as is the case with wheat and maize which have long benefited from western technology.

Since 1976, Carlsberg has studied the African situation with a view toward exploiting the resources of climatically adopted cereals such as sorghum (Eggum et al. 1982 and 1983, Munck et al. 1982, Axtell et al.

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Hallgren, L., Rexen, F., Petersen, P.B., and Munck, L. 1992. Industrial utilization of whole crop sorghum for food and industry. Pages 121–130 *in* Utilization of sorghum and millets (Gomez, M.I.. House, L.R., Rooney, L.W., and Dendy, D.A.V., eds.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

1982, Hallgren and Murty 1983, Hallgren 1984 and 1985, and Bach Knudsen and Munck 1985), and we have developed processing technology for urban areas for sorghum, millet, and maize which could constitute a market outlet for small farmers. Up to now the practical introduction of these possibilities has been slow, but due to the oil crisis and the lack of hard currency, African countries such as Nigeria are now attempting to stimulate local agricultural production as they curtail their imports. The energy crisis in Europe and the USA, as well as the large grain surpluses in these countries, have triggered new ideas for the utilization of renewable resources—the biomass—for the manufacturing industry (Rexen and Munck 1984). Hundreds of ideas to convert biomass have been suggested, such as ethanol for cars, plastic from starch, and paper and particle boards from straw. While these products could only be produced profitably at very high oil prices in the industrialized countries, the possibilities are realistic in developing countries which lack hard currency (Munck and Rexen 1985).

In this paper we will discuss our investigations of traditional food production in the modern manufacturing industry.

The Whole Sorghum Plant

A part of the strategy towards increased application of cereals in industry should be an endeavor towards utilization of the whole biomass of the sorghum plant. One of the main issues should be to maximize the utilization of the crop through optimal application of each botanical fraction. Figure 1 shows a drawing of the sorghum plant and illustrates how the whole plant can be transformed into intermediates for use in various industries.

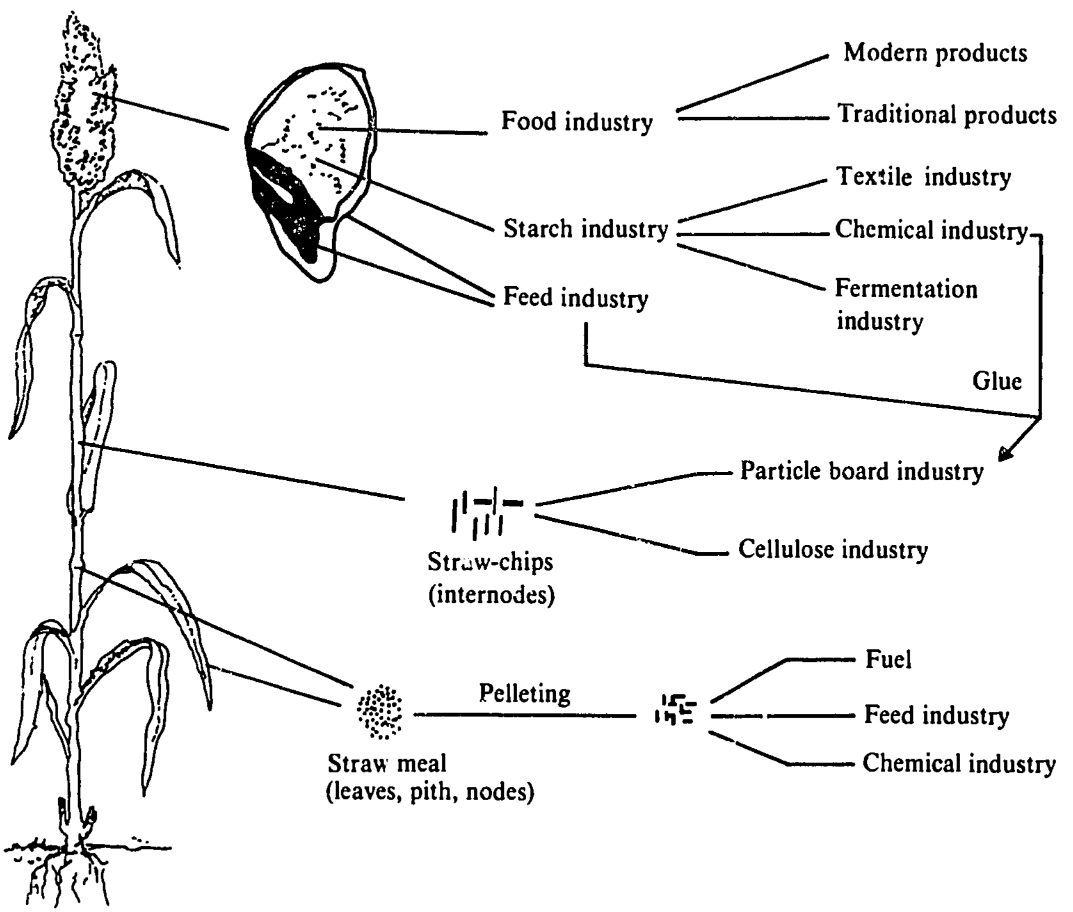

Figure 1. Transformation of the sorghum crop into intermediates for use in various industries (drawing by Milena Rasmussen).

Table 1. Chemical composition of internodes, nodes, and leaves from wheat and barley.

Species component	Wheat			Barley		
	Internode (%)	Node (%)	Leaf (%)	Internode (%)	Node (%)	Leaf (%)
Crude protein	2.9	4.5	4.8	1.7	4.0	3.7
Cellulose	41.1	32.7	32.3	43.3	33.2	36.4
Hemicellulose	42.5	28.6	25.6	24.2	33.1	28.3
Klason lignin	21.6	21.7	26.8	17.6	16.7	14.3
Ash	3.8	5.1	9.6	1.6	3.1	4.4
Silicon	1.4	1.5	3.9	0.3	0.4	1.1

Source: Theander and Aman 1984.

Separation of Botanical Components of Straw

Cereal straw consists of three major botanical components: nodes, leaves, and internodes (Fig. 1). The internodes are separated by nodes, which are the starting points of the leaves. The leaf blade and leaf sheath are parts of the leaf. The leaf sheath envelops the lower part of the internode. Maize and sorghum have high amounts of pith in their stems.

The components of straw have different physical strength properties. The leaves are very fragile, while the internodes are very tough. The internode part of the straw is therefore suitable for making particle board with quality comparable to wood.

The botanical components differ not only in physical characteristics but in chemical composition. Table 1 shows the chemical composition of hand-dissected wheat and barley straw (Theander and Aman 1984). A similar study remains to be done in sorghum. Data from machine-separated sorghum straw compared with other cereals are discussed later in this paper. Table 1 indicates that the internode fraction of wheat and barley is significant to the cellulose industry since it has a higher cellulose content, a lower ash content, and (very importantly) a lower silicon content than the whole straw. The content of silicon in straw is much higher than that in wood. Silicon is known to cause serious scaling in the boiler during evaporation of waste water in the straw cellulose industry.

The digestibility of the different botanical components of straw has been examined (Ramanzin et al. 1986). The individual parts have an increasing digestibility of energy in the following order: leaves, nodes, internodes. Thus, straw consists of a highly digestible part, the leaves, and a part, the internodes, with lower feed value but wide industrial use because of its higher cellulose content. Rexen and Knudsen (1984) showed that the digestibility of cereal straw can be improved considerably by spraying with a 4% solution of NaOH. Traditionally, high-tannin sorghum grains have been processed with alkali, and this treatment is known to have improved the nutritional quality. Consequently, apart from the improvements from changes such as solubilization of lignin and swelling of cellulose fibers, an effect due to the inactivation of polyphenols can be expected when leaves from high-tannin sorghum cultivars are treated with the NaOH solution.

Carlsberg has developed a special system for separating the different components of cereal straw (Fig. 2). After threshing the seeds, the straw can be mechanically separated into its botanical constituents (Petersen 1987). This is done on a special disc mill (Model MHA) developed and patented by United Milling Systems (UMS), a subsidiary of Carlsberg A/S, Denmark, in cooperation with us. The mill consists of stationary and rotary hard metal discs.

Dried, chopped straw material is ground in the mill with a distance between the discs of 0.9 mm. By this treatment the brittle leaves and nodes are milled to a fine meal powder, while the more elastic internodes are split up as coarse chips and separated from the adhering pith which joins the meal fraction. After grinding, the milled goods can, if necessary, be passed through a second disc mill. The discs of this mill are coated with carborundum. The mechanical treatment between the abrasive carborundum-coated discs further improves the breakage of the tubular structure and etch the wax layer of the internodes in order to obtain adhering sites for the glue. Our experiences have shown, however, that the first grinding (the hard metal disc mill) is sufficient for most of the cereal species investigated (barley, wheat, rye, and oats).

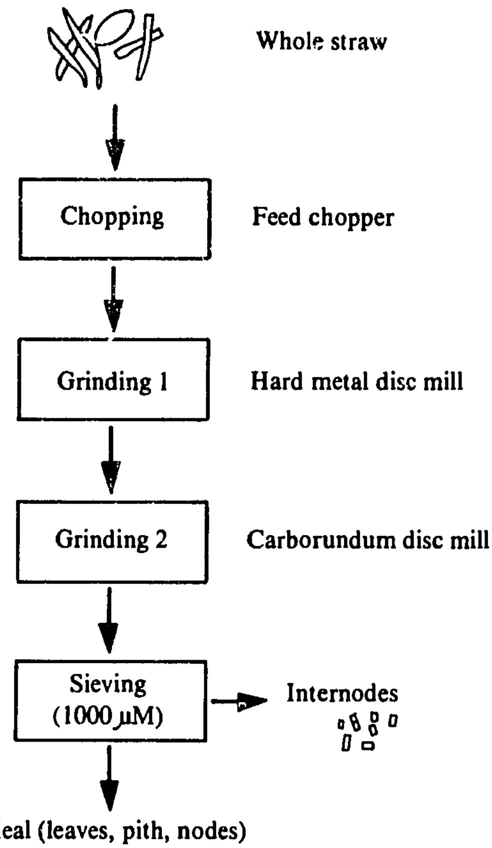

Figure 2. Mechanical separation of straw.

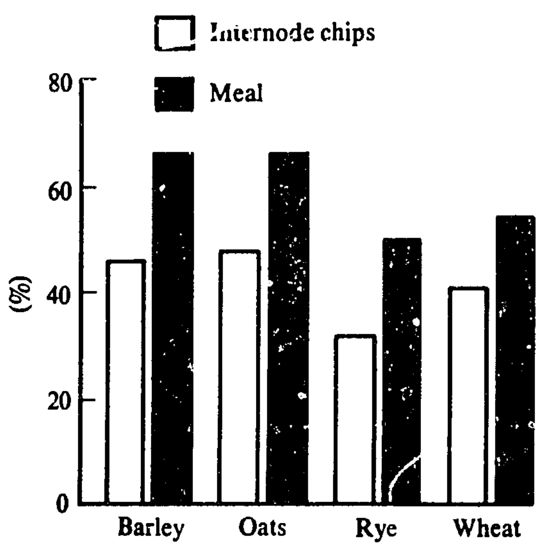

Figure 3. In vitro digestibility of mechanically separated straw fractions (48h) (Petersen 1988).

After the two grinding steps, the milled mass is sieved on a 1000 µM mesh screen into two fractions: an internode chip fraction suitable for particle board and paper pulp, and a meal consisting of ground leaves, pith, and nodes suitable for fodder or for pelleting for fuel. The mechanical separation has been applied to straw of barley, wheat, rye, oat, rape, maize, and sorghum. The results are shown in Table 2. Sorghum and maize contain large amounts of pith, and during milling of these species most of the pith disintegrated and was found in the leaf fraction (the meal was less than 1000 µM). More efficient separation can be effected by air sifting in order to obtain an internode fraction without any pith residues.

Table 2. The percentage of internode chips obtained by the straw separation process.

	Number of samples	Internode (%)
Spring barley (a)	5	51
Winter barley	12	47
Spring barley (b)	2	44
Winter wheat	6	46
Winter rye	5	57
Oats	2	56
Maize	5	36[1]
Sorghum	1	56[2]

1. All nonsorghum results are from Petersen 1987.
2. Maize and sorghum internodes ground in the milling system (cleaned for pith residues). The results are based on maize from Denmark and a sorghum cultivar (PN-3) from Nigeria.

Figure 3 shows the in vitro digestibility of mechanically separated straw fractions from different cereals (Petersen 1987). The meal and internode chips from wheat, barley, oats, and rye were tested in in vitro digestibility experiments performed by Dr Orskov of Rowett Institute, Scotland.

The meal, consisting of ground leaves and nodes, was found to have very high digestibility—even higher than that of the internode chips. This finding agreed with earlier results from manually separated material (Ramanzin et al. 1986). By use of the UMS disc mill, it was possible to separate the leaves from the internodes and thereby produce a meal with a feed value as high as hay or pretreated straw.

Particle Boards from Sorghum

During the last few years, we have experimented with the manufacturing of particle board from straw. This was done both on a laboratory basis and on a full-scale basis in cooperation with particle board industries. Although most of this work was concentrated on utilization of cereal species grown in Denmark, we also studied rice and sorghum straw. In our laboratory procedure, shown in Figure 4, the straw internodes are placed in a concrete mixer and the glue (with the hardener) is sprayed onto the chips while the mixer is running. After 5-10 min, the product is evenly distributed (by hand) into a matrix. The straw is then manually pressed in the matrix to a mat with a wooden plate. The matrix is removed and the mat transferred to the hydraulic press. After 10 min at 120°C with a pressure of about 25-30 kg/cm^2, the particle board is finished and tested (after cooling) in an Instron board tester.

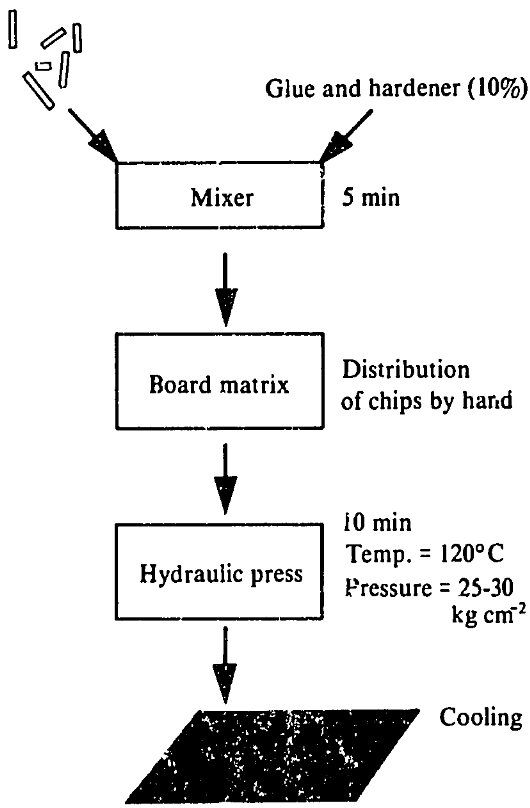

Figure 4. Laboratory procedure for preparation of particle board.

We compared the strength of a board made from 100% sorghum internodes with that of a board from 100% wood chips (Table 3). The results obtained from our preliminary experiments with sorghum straw indicate that the particle board made from sorghum straw was equal in strength to that of the control board made from wood (Table 3). The higher number obtained for the tensile strength of the wood board compared to the sorghum straw board was insignificant (at $P < 0.5$). Earlier experiments on Chinese sorghum straw harvested early (green straw color) resulted in inferior particle board. It is thus important that the straw be ripe when harvested and that the water content be around 10–12% to obtain the best separation of internodes in the milling process.

Table 3. Comparison of particle boards of sorghum internode chips and wood chips. Results are means and standard deviations from six determinations from the same board.

	Modulus of elasticity (N mm^{-2})	Modulus of rupture (N mm^{-2})	Tensile strength (N mm^{-2})
Sorghum internode chips	3237 ± 229	22.0 ± 1.8	0.30 ± 0.09
Wood chips	3257 ± 112	21.9 ± 1.8	0.39 ± 0.11

The glue is a very important component. In the experiment described here we used a relatively cheap urea/formaldehyde glue; however, the best glue for straw particles is a urea/formaldehyde glue modified with isocynate. This kind of glue can improve the tensile strength of a sorghum particle board.

Finally, we expect that more experimentation with sorghum straw in the milling process as well as further studies in selection of varieties with stronger internodes will result in boards of even higher strength.

Straw Cellulose for the Paper Industry

The stem or internode fraction from straw is excellent as a raw material both for particle board and paper production. The internodes have a higher cellulose content and a lower content of ash and silicon than the whole straw, while neither the nodes nor the leaves have much value as sources of fiber. The presence of leaves, sheets, and nodes in the pulp digester necessitates additional cooking chemicals and results in a lower pulp yield. Furthermore, the leaves are often discolored due to contamination with microorganisms, thus creating a higher demand for bleaching chemicals.

Straw is best suited for fine writing and printing paper and corrugated and solid board. It has been reported (Kuniak and Slavik 1960) that pulps of a domestic sweet sorghum could be used for the manufacture of high quality writing paper.

All writing and printing paper produced in Denmark contains average of 30% bleached wheat and rye straw cellulose. The other fibers come from wood pulp containing longer fibers.

Utilization of the Sorghum Grain

The botanical structure of a sorghum kernel consists of three major parts: pericarp, endosperm, and germ. Hand dissection indicates that the kernel is made up of 7-9% bran (pericarp and associated tissues), 8-12% germ, and 80-85% endosperm (Hubbard et al. 1950).

The endosperm can be divided into three important parts: the aleurone layer, the vitreous part, and the floury part. The proportion of vitreous endosperm to the whole endosperm is often referred to as the endosperm texture (Rooney and Miller 1982). The physical hardness of the vitreous part of the endosperm is much higher than that of the floury part. The hard endosperm protects the kernels against microbes and determines the ease of dehulling and the proportional yield of different mill streams.

Sorghum grain can be malted and used for the production of traditional African beer or in a mixture with precooked or extruded sorghum for weaning food in order to reduce the viscosity of porridges. The separation of botanical components by dry milling of sorghum has been reviewed by Reichert (1982). Much of the research was concentrated on the development of suitable dehulling equipment for sorghum, since other aspects of milling (cleaning, grinding, etc.) was less problematic. Carlsberg jointly developed a sorghum milling process with UMS based on a fine grinder and a specially developed UMS DVA-dehuller designed for sorghum (Munck et al. 1982).

A comparative study was recently initiated by the International Association for Cereal Science and Technology to evaluate different dehulling systems using the same raw material. Our part of this study (Hallgren et al. 1988) indicated possible ways of making full-scale predictions based on dehulling tests in microscale (Hallgren et al. 1988). We compared three different dehullers: a full-scale dehuller from UMS, a laboratory carborundum dehuller from Schüle (Germany), and a portable microscale dehuller from Kett Electronic Industries (Japan). Our results from the comparative study indicated that the small dehuller with a capacity of only 3-10 g could be used to predict the full-scale dehulling performance (100 kg h^{-1}) for sorghum cultivars of different physical characteristics.

In the UMS industrial processing system, the dehulled kernels are ground to flour by a fine grinder. The fine grinder can be either a vertical disc mill or a high-efficiency horizontal rotary grinder. The grinding principle and the maintenance cost are very important. The energy required for grinding is also important and is related to seed hardness and the desired particle size of the flour. Figure 5 shows a flow diagram for the UMS sorghum processing system. The idea is to utilize the whole grain for different traditional and modern products as well as for the chemical industry.

Successful milling processes must consider the differences in physical hardness between the mealy and vitreous parts of the endosperm (Hallgren 1984). During grinding the mealy part will pulverize more easily than the much harder vitreous part. The process consists of a dehulling step, a sieving step, and two grinding steps.

The residues from the dehulling (bran and germ) can be used in the feed industry or as fuel pellets. The polyphenols of the bran of high-tannin sorghums could be used together with starch from the flour for the manufacture of glue for the particle board industry. Results in our laboratory have shown that it is possible to produce a carbohydrate-modified phenoformaldehyde glue based on either glucose, wheat starch, wheat flour, or maize starch (Frandsen 1987). By modifying the carbohydrate, both phenol and formaldehyde could be saved. Industrial adhesives have been made from condensed tannins of sources other than sorghum (Ayla 1984, Hemingway and Kreibich 1984, Pizzi and Roux 1978). More research is necessary, however, to determine whether polyphenols from sorghum can be utilized in a glue process with sorghum flour or starch to make high-quality water-resistant glue for particle board of sorghum internodes.

The dehulled grain can be further ground, used as a raw material in extrusion cooking, or sold as a product similar to polished rice. The first milling step is a coarse grinding. A high amount of coarse grits will be produced during this grinding and the flour from the sieving will have a relatively low content of damaged starch (Hallgren 1985). Starch can easily be extracted from this flour by wet milling. This flour has the best gelatinization properties (i.e., the starch granules are well integrated in mixtures with wheat in composite flour baking). This fraction may also reduce the mouth feeling problem ("sandiness") in food

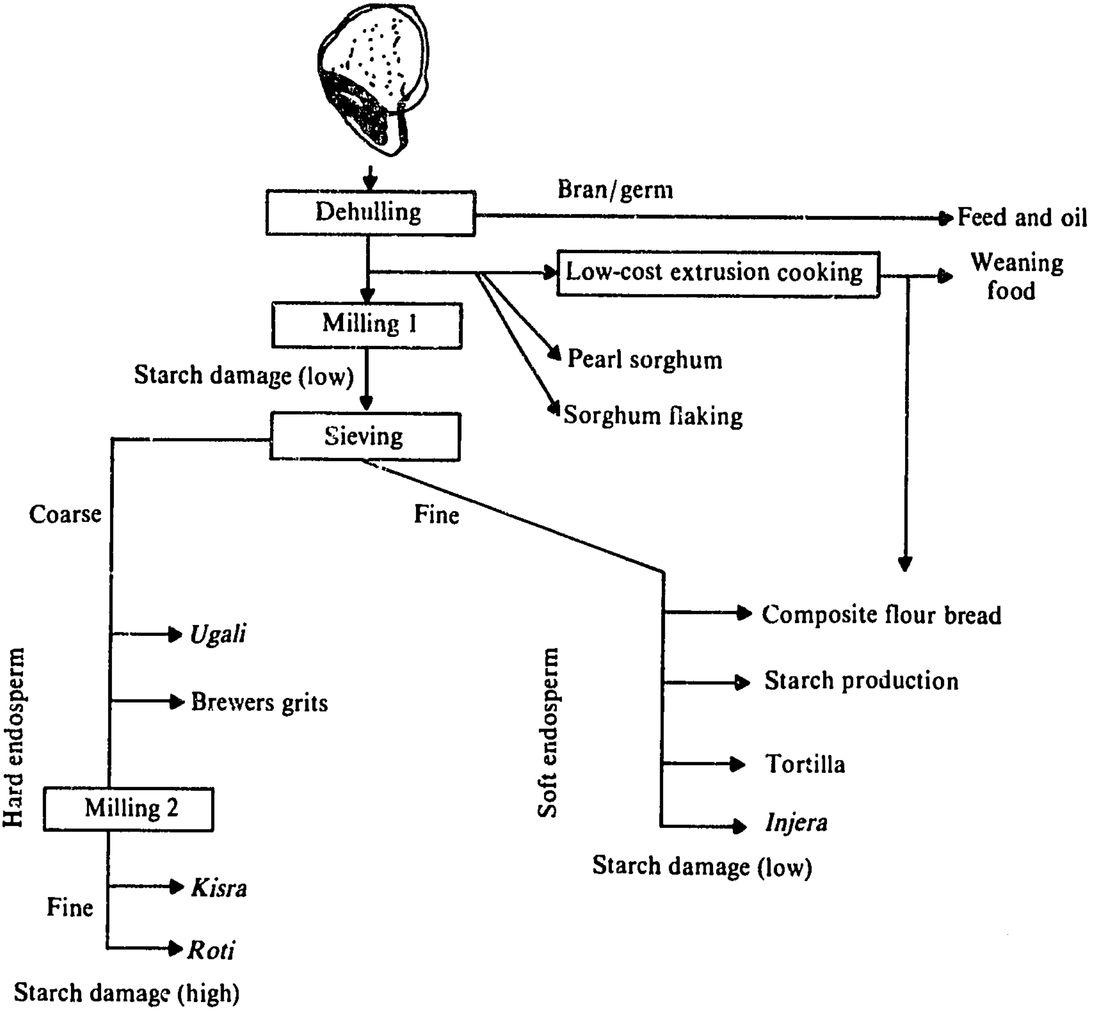

Figure 5. Industrial sorghum processing.

prepared from sorghum and wheat flour blends. The coarse grits fraction from the first milling step produce high quality brewers grits (an adjunct in traditional and lager beer) and may also be utilized in traditional thick sorghum porridges (*ugali*, *asida*, etc.).

Finally, the grits are ground to a fine flour. In this step a high amount of damaged starch is produced. A high level of starch damage results in a sticky dough when mixed with water (Hallgren 1985). This property is expected to be beneficial in the preparation of flatbreads like the Indian *roti* and the Sudanese *kisra*.

Examples of Industrial Applications

Two examples of industrial applications of sorghum grain and one example of sorghum straw are cited below.

Industrialization of local food habits based on local raw materials

The importance of fermented beverages and porridges has been well described by Novellie (1982).

The sourness of these products has great appeal to the African palate. The high acidity of the products (low pH) keeps pathogens from proliferating, an important point in areas of contaminated water supplies.

Today, African sorghum beer is brewed locally and manufactured in large modern plants. In industrial production, the favored sourness of beer is obtained either by natural fermentation or by the addition of lactic acid. *Ogi* is an important thin porridge made locally by fermentation. Fine flour is needed for *ogi* preparation. During this process, which includes a wet milling step, a high proportion of dry matter is lost due to a necessary screening step. Carlsberg was recently involved in an *ogi*-mix project in Nigeria. The plant consists of a mill for grinding maize, sorghum, and cowpea, and a production line for *ogi*-mix. The mill has a capacity of about 1000 kg sorghum (or maize) h^{-1}. The *ogi*-mix is made into a fine flour by dehulling and dry milling prior to spraying with a blend of natural acids and flavor components. The consumer prepares the *ogi* simply by pouring boiling water into the powdered mix.

Sorghum as a substitute for imported wheat in biscuits

In Nigeria, the import of wheat is no longer permitted, and only limited amounts can be grown in the country. Consequently, new ways of utilizing local crops are needed. Sorghum and millet can to some extent be used in mixtures with wheat in composite flour bread and in cakes (Hallgren 1984). However, one of the most promising uses of sorghum flour is in biscuits and wafers where 100% sorghum flour can be used. Sorghum is preferable to maize because it is more neutral in taste. The functional properties of the wheat gluten protein is important in the composite flour baking (French bread), but is not desirable in biscuits and wafers.

We have experimented in the laboratory with biscuit baking and found that the cohesiveness of the dough made from 100% sorghum flour could be improved by addition of locust bean gum or guar gum (Grondal 1988). Sorghum biscuits could be further improved by adding extruded sorghum flour obtained from a low-cost cooking extruder.

Starch glue for particle boards

Most of the raw materials used to produce synthetic adhesives are petrochemicals, or are derived from them. Synthetic resins are the most expensive components of particle board. For this reason, research is being conducted in many countries to find a substitute for glue components which can be produced locally.

We have shown that wheat starch or wheat flour can replace glucose in a phenolformaldehyde glue formula (Frandsen 1987). Sorghum starch or flour may be used in a similar way to save the expensive phenol component. Another possibility is to substitute a part of the phenol with compounds of phenolic structure like tannins. The tannins may be extracted from different local sources, like the black wattle tree. More research is needed, however, to investigate the possibilities of using polyphenols from high-tannin sorghum varieties or other local sources in combination with sorghum starch or flour and sorghum internodes for local production of particle board.

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Discussion

O. Olatunji: What is the industrial potential for sorghum utilization in Denmark?

L. Hallgren: Sorghums are not grown in Denmark and consequently we do not utilize it industrially. Wheat and rye straw are intensively used in the production of paper pulp in Denmark's cellulose industry.

A.C. Moshe: Could you tell us something about Carlsberg's effort to make beer from sorghum?

L. Hallgren: Carlsberg brews lager beers in Malawi (Blantyre) using barley malt, and grits of maize or sorghum as an adjunct. Next door, Chibuku produces an excellent opaque beer. We have no plans of such production. The two products are taxed differently and have different production costs. They also have different consumer groups. Consequently, they do not compete.

O. Olatunji: What is the comparative assessment of *ogi* made by dry milling and wet milling. Based on the experience that cooking reduces digestibility of sorghum, will you recommend the dry milling method?

L. Hallgren: *Ogi* mixed with boiling water may display slightly different textural properties compared with traditional preparation by wet grinding and long fermentation. However, we are still improving the *ogi*-mix product in terms of texture, taste, and nutritional properties.

J.E. Cecil: Sugar is detrimental in making particle board—it seriously affects the strength of the bond with most resins. This is why there is so much difficulty with bagasse. Are you using a special bonding agent, or how do you remove the sugar?

L. Hallgren: In the preliminary experiment, we used a relatively cheap urea-formaldehyde glue. However, this may not be suitable for particle board made from sorghum internodes.

Sweet Sorghum Substrate for Industrial Alcohol

R.E. Schaffert[1]

Abstract

Sweet sorghum may be used as the raw material for biological transformation into ethyl alcohol, utilizing the same infrastructure and equipment as that utilized in transforming sugarcane into alcohol. In tropical conditions, the harvest periods of these two crops complement one another, allowing for a longer period of alcohol production. Cultural management to ensure a constant supply of the raw material for transforming into alcohol depends on the knowledge of the period of industrial utilization (PIU) for each cultivar used for each planting period. This has led to a definition of a PIU for sweet sorghum and managing the crop for up to several months. The breeding program at CNPMS/EMBRAPA has developed new sweet sorghum cultivars for tropical conditions, utilizing the PIU developed at EMBRAPA, with a 10% increase in alcohol production over the best cultivar previously available. Research priorities are discussed, as is integrated utilization of sweet sorghum for alcohol production and for food, feed, and forage. In central Brazil, real alcohol yields greater than 2500 L ha⁻¹ have been obtained from biomass yields between 40 and 50 t ha⁻¹.

Introduction

Sweet sorghum (*Sorghum bicolor* [L.] Moench), because of its juicy, sweet stalks, has been a subject of scientific investigation for over 150 years (Cowley and Smith 1972). Interest in sweet sorghum is especially important in areas of the world where other sources of sugar are difficult or impossible to produce. Its importance also increases during years when imported sugar supplies are threatened or interrupted by political or economic problems. Sweet sorghum has been used for over 100 years to produce a concentrated syrup. Sweet sorghums may differ from grain sorghums by only a few genes: those controlling plant height, the presence of juice in the stem, and the presence of sugar in the juice. Sweet sorghums have also been widely used for the production of forage and silage for animal feed.

Some varieties of high sucrose sweet sorghum for crystallized sugar production were developed by the US Department of Agriculture (USDA) and the Texas Agriculture Experiment Station with the idea of prolonging the milling period of sugar factories since the milling periods of sugarcane and sweet sorghum complement each another (Cowley 1969). With the development and release of the varieties Rio, Roma, and Ramada and the development of a method for crystallizing sugar from sweet sorghum juice in the early 1970s (Smith et al. 1970), it became possible to produce crystallized sugar from sweet sorghum juice. A pilot industrial run confirmed the viability of the process in the Rio Grande Valley of Texas in the late 1970s. The following year, however, the world price of sugar dropped and the production of sugar from sweet sorghum has remained unprofitable since then.

The oil crises of 1973 and 1976 renewed interest in the commercial production of sweet sorghum for biological transformation into ethyl alcohol for use as fuel and fuel additives. (Schaffert and Gourley 1982). In 1975 Brazil created a national alcohol program

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(PROALCOOL) that resulted in a dramatic increase in alcohol production, principally from sugarcane (Schaffert et al. 1986b). In 1987, nearly 14 million m^3 of alcohol were produced to operate a fleet of approximately 3 million alcohol motor automobiles. Interest was also generated to produce alcohol from other biomass courses. Sweet sorghum was considered a good choice because it can be processed in a sugarcane mill and the harvest periods of sweet sorghum and sugarcane complement each another, increasing the potential milling period by 3 or 4 months to a 9-10 month milling period.

The great concentration of large distilleries (120 000 to 2 million L day^{-1} capacity) and unavailable land space initially made the idea of processing sweet sorghum for alcohol impractical. However, the idea of using micro-developing and mini-distilleries (1000-20 000 L day^{-1} capacity) in outlying areas for fuel self-sufficiency on large farms, as well as for small cooperatives and outlying small communities, awoke interest in the use of sweet sorghum for alcohol production. In central Brazil, which is agroclimatically similar to the SADCC countries, the harvesting period for sweet sorghum is from late February to May. Sugarcane is normally harvested from June to November.

There are several advantages to using sweet sorghum instead of sugarcane, as the biomass source for alcohol production.

- Sweet sorghum may be harvested in 4 months (whereas the first cut of sugarcane is 18 months after planting).
- Sweet sorghum production can be completely mechanized.
- The sweet sorghum crop is established from seed.
- Sweet sorghum grain may be used as either food or feed.
- The bagasse from sweet sorghum has a higher biological value than the bagasse from sugarcane when used as a forage for animals.

Development of Sweet Sorghum Cultivars in Brazil

Because of the strong influence of the sugarcane industry on policymaking in Brazil and the misconception concerning correct sugar levels that arose, the cultivation of sweet sorghum as an adequate biomass source for alcohol production in Brazil was severely delayed.

Breeding Methods for Sweet Sorghum Improvement

In order to successfully carry out a breeding program for crop improvement, the plant breeder must have a thorough understanding of how the end product will be used. In the case of sweet sorghum, whether for sugar or alcohol production, a complete knowledge of the transformation process and the period of the industrial process must be known. In this paper the improvement of sweet sorghum for transformation into alcohol is considered.

The sweet sorghum breeding improvement program in Brazil (Schaffert et al. 1986a) was initiated in 1980. It was decided that the stalks and leaves of sweet sorghum would be milled in micro- and mini-distilleries in central and southern Brazil during the season when sugarcane is not normally milled (February to June). The normal planting season for annual crops begins in October and November with the first rains of the cropping year. A 100-day sweet sorghum cultivar planted at the beginning of November could be harvested in February and the ratoon crop could be harvested in June. Considering that day length decreases from December to June, the cultivar used must be nonsensitive to photoperiod daylength. Because the stalks and leaves remain green, the separation of the two components is difficult, whether by manual or mechanical methods. The stalks and leaves are therefore milled together. The panicles and grain are removed for their food or feed value and because of possible interference during the extraction of sugars and the subsequent fermentation and distillation processes.

In micro- and mini-distilleries the sugars are extracted from the plant material by crushing in a three-roller mill or a tandem of three-roller mills with the liquid phase of the raw material. The juice is then fermented with brewer's yeast. The fermented juice is then distilled to a minimum of 92% ethyl alcohol for use as a motor fuel or in the alcohol chemical industry (Schaffert and Gourley 1981). The 92% alcohol may be redistilled to produce absolute alcohol for mixing with gasoline.

Minimum Quality Requirements

The energy input required during the distillation process requires that the maximum degree of alcohol in the beer be obtained during the fermentation process. The biological limit of this process today is between 8 and 9% alcohol. The ideal conversion factor of simple sugars to alcohol is 0.64755. It is therefore necessary to have a sugar content of 12.35% in the juice to produce an alcohol content of 8% under ideal conditions. Normally the juice is diluted to a sugar content of 14-15% for maximum fermentation efficiency. For the purposes of our breeding program, we consider an inferior limit of 12.5% fermentable sugars in the juice. There is no superior limit.

Culture Management

Normally all distilleries in Brazil operate with sugarcane and those that use sweet sorghum will use it for a period ranging from 60 to 120 days (and possibly longer) when the ratoon crop is considered. A cultivar of sweet sorghum normally reaches a peak sugar content about 30 days after flowering and then declines. The decline of sugar content varies from one cultivar to another and from one year to another. In order to have sweet sorghum with a sugar content in the extracted juice superior to 12.5% every day for the programmed harvest period, it is necessary to know the period for industrial utilization (PIU) for each cultivar. In our program we have established a minimum PIU of 21 days for cultural management. It is possible to program a 60- to 120-day or even longer harvest period, either by using cultivars with different maturities or by sowing the same variety at different sowing dates.

Minimum Alcohol Yield

For the sweet sorghum crop to be economically feasible, it is necessary to establish a minimum alcohol yield per t of stalks and leaves as well as a minimum biomass yield. We have considered a minimum of 40 L alcohol t^{-1} biomass (stalks and leaves) for micro- and mini-distilleries, and a minimum biomass yield of 40 t ha^{-1}. Considering 90% efficiency during the fermentation process and 90% efficiency during the distillation process, the overall industrial efficiency is 0.9×0.9, or 81%.

The minimum amount of extractable sugar t^{-1} biomass (stalks and leaves) necessary to give an alcohol yield of 40 L t^{-1} with an overall industrial efficiency of 81% is 76 kg. In our program we have considered a minimum of 80 kg of extractable sugars t^{-1} biomass for determining the minimum values for calculating the PIU. The efficiency of sugar extraction would be better in a large distillery (approximately 90-95% instead of 60-65%).

Determining PIU

Each new cultivar developed in our breeding program is characterized by the PIU. We use a hydraulic press that closely approximates the extraction of a three-roller mill (245 kg/cm^{-2} for the duration of 1 min). Replicated field samples of a minimum of 10 stalks with leaves and panicles removed are harvested at regular intervals (7 or 14 days). Each stalk and leaf sample is run through a forage chopper for maximum open-cell preparation. A 500 g sample is pressed and the percentage of extracted juice is calculated. The juice is then immediately analyzed for brix (soluble solids), reduced sugars, and total sugars. Moisture and fiber content are also determined.

A response curve is determined and plotted for each parameter using the regression technique. The possible variation between cultivars and between years is demonstrated in Figures 1 to 4 for juice extraction, fiber, brix, total sugars (juice) and total sugars extracted. The PIU is for the time period that extracted sugars are greater than 8 kg per 100 kg biomass.

The year 1981 was characterized by an excessive amount of rain. The variety Brandes is a syrup-type sweet sorghum with low sucrose. It was developed at Meridian, Mississippi by the USDA and Mississippi State University (Coleman and Broadhead 1968). Brandes is photoperiod sensitive, and generally produces a large amount of grain. In some environments, it does not meet the minimum standards of the PIU for even 1 day, whereas in other environments it has a PIU of around 30 days. The variety Wray, a high-sucrose cultivar developed by USDA and the Texas Agriculture Experiment Station, is photoperiod nonsensitive and characterized by a small panicle and low grain production. This cultivar has an excellent PIU which in some years is greater than 60 days. The cultivar Wray is generally less productive in biomass production than the cultivar Brandes in periods of long daylength in central Brazil. In periods of short daylengths the production of Brandes is greatly reduced and resembles a grain sorghum cultivar.

New Cultivars

Two new sweet sorghum cultivars for alcohol production, BR 506 and BR 507, derived from the cross of

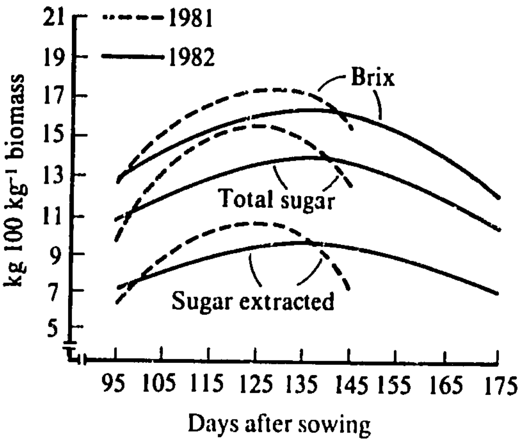

Figure 1. Brix total sugar and extracted sugars for cultivar Brandes at Araras, CNPMS/ EMBRAPA, 1981 and 1982 (Schaffert et al. 1986).

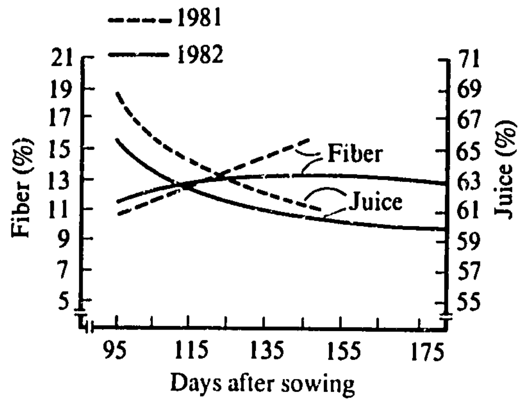

Figure 3. Percent fiber and juice extraction of cultivar Brandes at Araras, CNPMS/EMBRAPA, 1981 and 1982 (Schaffert et al. 1986).

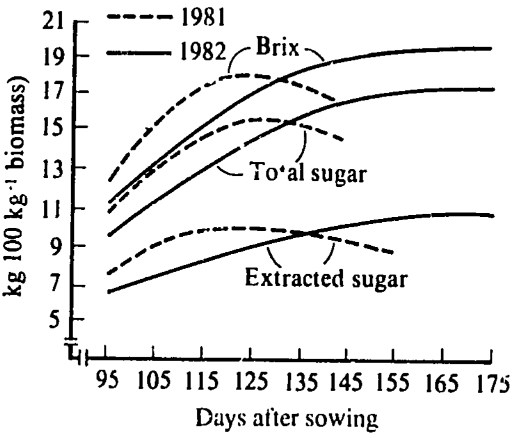

Figure 2. Brix total sugars and extracted sugars for cultivar Wray at Araras, CNPMS/ EMBRAPA, 1981 and 1982 (Schaffert et al. 1986).

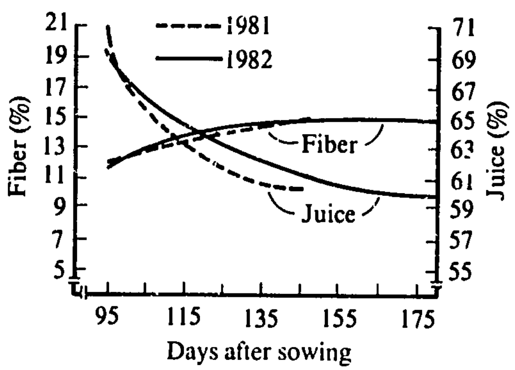

Figure 4. Percent fiber and juice extraction of cultivar Wray at Araras, CNPMS/EMBRAPA, 1981 and 1982 (Schaffert et al. 1986).

Table 1. Biomass and alcohol production of two new cultivars, BR 506 and BR 507, compared to Brandes and Wray.

Cultivar	Biomass production	Extracted sugar yield		Alcohol yield Ideal	Alcohol yield 81% Efficient	Alcohol yield Relative
	(t ha^{-1})	kg 100 kg^{-1}	(t ha^{-1})	l ha^{-1}	l ha^{-1}	Wray
Brandes (BR 501)	47.4	7.2	3.4	2208	1788	75
Wray (Br 505)	44.6	10.9	4.6	2946	2386	100
BR 506	48.8	9.7	4.7	3062	2481	104
Br 507	52.0	9.6	5.0	3231	2617	110

Source: CNPMS/EMBRAPA 1986/87.

Brandes × Wray, was developed by CNPMS/EMBRAPA for central Brazil. The cultivars, selected for high extractable sugar and a stable PIU (greater than 21 days), were released in 1987. Both varieties are photoperiod nonsensitive, have excellent disease resistance, are intermediate in grain production, and have high biomass production. The PIU of both cultivars is excellent, comparing well with Wray and definitely superior to Brandes. The characteristics are summarized in Table 1 and Figures 5 to 10.

Conclusions

The emphasis on alcohol production in Brazil and in the USA has been reduced during the past few years, principally because of the cheaper price of crude oil and fuel substitutes, and in the case of Brazil because of overproduction of alcohol. This in pa' : also reflects reduced demand and price of sugar on the world market. Alcohol can be produced in small- or large-scale distilleries with nearly the same level of efficiency.

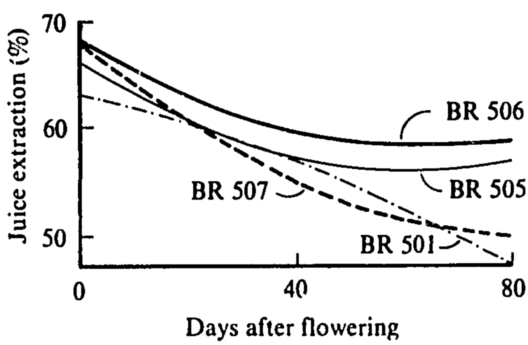

Figure 5. Percent juice extraction of four sweet sorghum cultivars at CNPMS/EMBRAPA, Sete Lagoas, 1986/87.

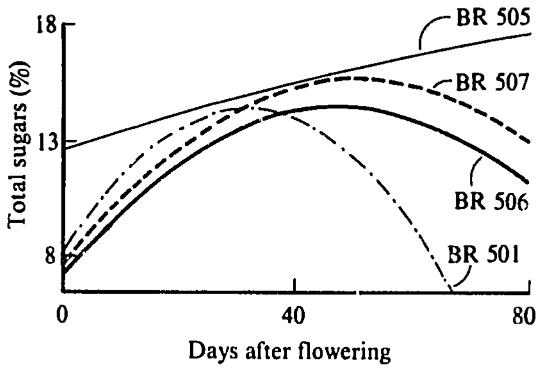

Figure 7. Percent total sugars in the juice of four sweet sorghum cultivars at CNPMS/EMBRAPA, 1986/87.

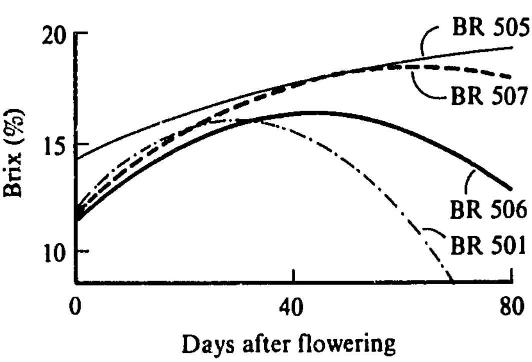

Figure 6. Percent brix in the juice of four sweet sorghum cultivars at CNPMS/EMBRAPA, Brazil, 1986/87.

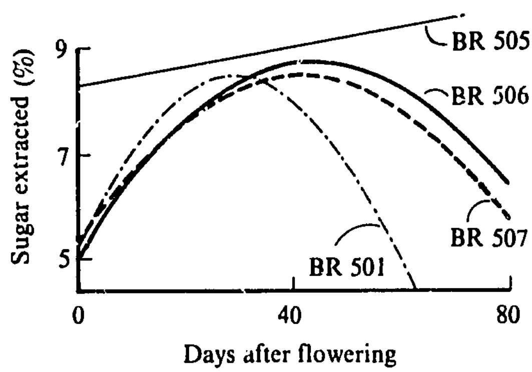

Figure 8. Sugar extracted (kg 100 kg^{-1} biomass) for four sweet sorghum cultivars at CNPMS/EMBRAPA, 1986/87.

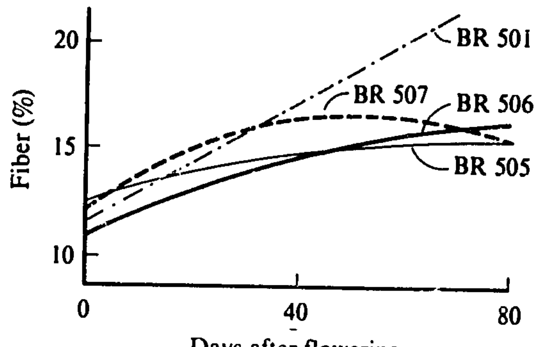

Figure 9. Percent fiber of fresh biomass of four sweet sorghum cultivars at CNPMS, 1986/87.

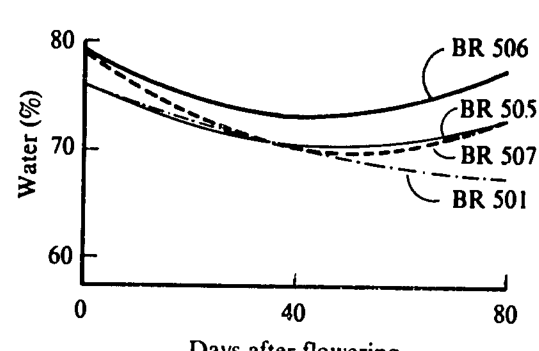

Figure 10. Percent water in the biomass of four sweet sorghum cultivars at CNPMS/EMBRAPA, 1986/87.

EMBRAPA has developed a small-scale horizontal inclined diffusor for extracting residual sugar from bagasse that has been as efficient in test runs in extracting the sugar from biomass as the large-scale distilleries. This in effect reduces the overall cost of production as the capital investment of installed liter-per-day capacity is greatly reduced and the transportation distance of the biomass is also reduced.

The production results of the sweet sorghum cultivar Wray, evaluated at the National Maize and Sorghum Research Center of EMBRAPA, indicates that approximately 2500 L ha^{-1} alcohol can be produced from one harvest of sweet sorghum in a small distillery with an 80% transformation efficiency during a 4-month growing period. The ratoon crop may be used either for alcohol production or for animal forage.

In one cycle of sweet sorghum improvement, a gain of 10% has been obtained in alcohol production. In a sweet sorghum improvement program, it is necessary to also select for an adequate PIU in addition to maximum sugar production. Industrial change from a roller mill to the more efficient technique of diffusion to extract sugars signifies that a change in breeding methodology may be made for selecting for maximum total sugar production.

Most of the earlier varieties evaluated (Brandes, Theis, Rio, Roma, etc.) were inadequate for maximum alcohol production. Adequate cultural practices need to be developed for the nearly released cultivars, including crop ratooning. Photoperiod insensitive cultivars must be identified for sweet sorghum where all the top growth is removed. All development needs to be made within an integrated management system which also utilizes the grain and bagasse.

The policy to explore alcohol production in Brazil using small distilleries (1000-20 000 L day^{-1}) did not develop extensively for several reasons. The early small distillery prototypes were not as efficient as planned, even though the later models were greatly improved. The price of crude oil dropped, making other forms of fuel more economical. Also, Brazil actually had a glut of alcohol when farmers worked hard to meet the alcohol production target ahead of schedule. The incentives for establishing micro- and mini-distilleries were consequently reduced.

Recommendations

The production of alcohol from sweet sorghum, considering only the value of the alcohol at production levels of 2500-3000 L ha^{-1}, will probably not ever be economical compared to other sources of alcohol. However, if the value of the subproducts is also considered, the use of sweet sorghum for alcohol production is more viable. Normally, 2-3 t of grain and approximately 16 t of bagasse (40 t biomass ha^{-1}) are also produced. In Brazil, in vivo digestibility values of 55% have been obtained in feeding trials of untreated sweet sorghum bagasse. Forms of treatment exist that can improve the digestibility value of bagasse considerably. The bagasse also has value as a soil conditioner in horticultural production and as a source of cellulose.

The total economic value of the various sub-products as well as policy issues must be considered when conducting an economic analysis of the viability of producing alcohol from sweet sorghum.

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Potential and Practice Relating to Sorghum as a Source of Sugar in Parts of India[1]

A.R. Ghanekar, C.D. Basarkar, and N. Nimbkar[2]

Abstract

Sweet sorghum could be grown successfully in India, especially in areas where sugarcane processing units are established. This would help extend the running period of sugar factories and small-scale jaggery units, thereby creating additional employment. The major problems with available sweet sorghum cultivars are low stalk yields, susceptibility to pests, photothermosensitivity, long duration, and poor grain quality. Keeping these drawbacks in view, a breeding program was conducted during the last 10 years, and these problems were efficiently addressed to make the crop economical for sugar production in certain areas. The high starch and aconitic acid content posed a major hindrance in processing the crop for sugar production. The problems of jaggery production were overcome due to the development of a suitable technology at our Institute. The large-scale cultivation of sweet sorghum poses two major obstacles: uneven maturity of the crop and a short harvesting period due to the perishable nature of the crop. Because of these reasons, the crop is not being utilized for large-scale sugar production. The problem of uneven maturity has been solved to some extent by developing suitable hybrids. The problem of a limited harvesting season remains.

Introduction

Sweet sorghum (*Sorghum bicolor* [L] Moench) is a versatile crop which can be grown for grain, forage, silage, syrup, and sugar production. The crop can be sown over a wide range of climatic as well as soil environments. In addition, it is an alternate source of renewable energy (Reeves et al. 1979; Smith and Reeves 1979, 1981). Interest in sweet sorghum as a commercial source of sugar in the USA is based on its desirable agronomic characteristics and its sugar content (Smith et al. 1972), but for a variety of reasons sugar production has never been sufficiently commercialized to establish a sorghum sugar industry. Various factories attributed their failures to one or more of the following reasons:

- lack of pedigree seed to provide plants to give a reasonably constant percentage of crystalline sugar;
- the rapid loss of sucrose in the stalk between harvest and juice extraction;
- crudeness and inefficiency of processing machinery;
- a short crushing period and an uneven maturity period;
- a depressed world market price for sugar; and
- difficulty in removal of starch and aconitic acids.

Some of the problems encountered in these early sugar production efforts have been resolved as more effective sugar technologies evolved in the sugarcane and sugarbeet industries. Starch and aconitic acid levels ranging from 1-4% on the basis of juice solids were major problems for early investigators since removal of these constituents was not required in the established technologies for processing sugarcane or sugarbeet juice. Without effective elimination of the starch, the gummy matter noted by Wiley (1883) interfered with sucrose crystallization. Unless aconitic acid could be reduced to negligible levels, insoluble aconitates formed as smear crystals to interfere with the separation of the sugar crystals from the molasses. The problem related to processing machinery for ex-

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Ghanekar, A.R., Basarkar, C.D., and Nimbkar, N. 1992. Potential and practice relating to sorghum as a source of sugar in parts of India. Pages 139–142 *in* Utilization of sorghum and millets (Gomez, M.I., House, L.R., Rooney, L.W., and Dendy, D.A.V., eds.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

traction of high percentage of sucrose from sweet sorghum stalks is still unsolved. The processing machinery used for sugarcane is costly, mechanically complex, and requires a large quantity of cane to reduce production costs (Elawad et al. 1979). Most sweet sorghum is grown for syrup production in the USA and processed on farms using small-scale three-roller mills for extraction of juice (Hemmerly 1983). For economical on-farm production of raw sugar, capital investment must be kept low. Very little information is available on this aspect. The literature also reveals that very scanty research data are available regarding yield levels, photothermosensitivity, pests and diseases, and quality of grain of sweet sorghum in the Indian subcontinent.

The research work undertaken at the Nimbkar Agricultural Research Institute during the last 10 years to explore practical means of producing raw sugar (jaggery) from the juices of sweet sorghum cultivars is reported in this paper. The achievements resulting from efforts to solve the problems of photothermosensitivity of various sweet sorghum cultivars (Table 1) and low stalk yields are also reported herein.

Jaggery Production

Jaggery is a traditional raw sugar product prepared mainly from sugarcane juice by Indian farmers. It is a solid sugar mass with a characteristic smell, color, texture, stickiness, and taste. A major limitation of sugarcane is that it is a long-duration crop requiring massive irrigation throughout the year. It is the basic raw material for India's sugar industry. Nearly 55% of the cane produced is used for jaggery and *khandsari* production (Rao 1985). The juice extraction percentage on the three- or five-roller mills used in jaggery manufacturing is 50-55% compared with 80–85% in sugar factories (Padalkar 1974). This is a national loss, especially when 1 million t sugar worth nearly US$ 400 million had to be imported in 1985.

Utilization of sugarcane for jaggery production thus affects the well-established sugar industry in India. If jaggery, which is an essential item of the rural Indian diet, is prepared from sweet sorghum juice, all the sugarcane could be diverted to the crystalline sugar industry, thus producing a complementary effect on the sugar industry. When the work on production of jaggery from sweet sorghum juice was initiated at our Institute, we understood that its manufacture would be carried out mainly at the village level by unskilled laborers using traditional equipment. There is no doubt that farmers will accept new technologies and processes provided the cost is low. The quality of jaggery is difficult to define because of its subjectivity. The chemical criteria of juice necessary for good quality jaggery are high values of brix, sucrose percentage, purity, and pH. These should result in jaggery with low reducing sugars, ash content, and electrical conductivity. We modified the process described by Hapse et al. (1978) for production of jaggery from sugarcane juice to suit the processing of

Table 1. Performance of various entries in different seasons, 1985-87.

Entry	Stripped stalk yield (t ha^{-1})				Total height (cm)				Maturity (days)			
	M85	W85/86	M86	W86/87	M85	W85/86	M86	W86/87	M85	W85/86	M86	W86/87
N-7	54.4	54.0	52.0	-	340	246	345	-	103	113	97	110
N-11	46.0	34.8	48.0	39.0	368	235	335	269	107	117	99	113
N-133	70.0	41.2	60.0	-	317	254	315	-	108	115	102	114
N-160-1	56.0	58.0	56.0	43.0	329	257	320	294	110	127	107	121
N-169	64.0	50.0	52.0	38.0	339	253	310	271	103	122	100	114
N-173	50.8	64.4	72.0	39.0	345	309	340	289	110	128	105	117
N-212	62.0	56.0	61.0	36.0	352	234	330	192	105	116	99	110
N-220	50.0	40.0	60.0	34.0	335	278	320	266	111	118	105	114
NSSH-1 (Hybrid)	-	-	54.0	48.0	-	-	282	239	110	115	107	110
NSSH-2 (Hybrid)	-	-	58.0	50.0	-	-	286	260	113	123	110	115

M = Monsoon season (Jul-Oct).
W = Winter season (Oct-Feb).

Table 2. The optimal and tolerable limits for different parameters for good quality jaggery.

Parameters	Optimal conditions	Tolerable limit
Harvesting stage	Milk stage	30 after grain maturity
Stripping of stalks	Clean, stripped	Only leaf lamina removed
Stage of stalks	Should be crushed within 3 h after harvest	Can be crushed within 15 h after harvest
Clarification	Use of okra stem juice	-
Removing of scum	Continuous removal of scum	Scum removal at the beginning and at syrup stage only
Boiling of juice	Initial rapid boiling needed	
Syrup stage	Addition of superphosphate solution. 10 g 100 L^{-1} juice and 10 mL lemon juice 100 L^{-1} juice	Lemon juice can be eliminated
Pan removal	Hard ball formation	
Crystallization	Stirring of mass on floor 10 min after the hot jaggery is poured	Stirring of jaggery mass on floor 20 min after the hot jaggery is poured
Storage	Storing in polythene bags	
Additives	Cane-sugar 500 g 100 L^{-1} juice	

sweet sorghum for jaggery production (Table 2). This includes the harvesting stage, stripping of the stalk, storage of stalks, clarification of juice, scum removal, boiling of juice, pan removal, crystallization, filling of molds, and storage (Ghanekar 1987). The final product was comparable to sugarcane jaggery. It was also found that the stalks can be harvested after grain maturity and that clean-stripping is not essential to obtain good quality jaggery. A jaggery unit manned by six laborers can process 4 t sweet sorghum stalks yielding 250–300 kg jaggery in one 8-h day. On-farm production of jaggery from sweet sorghum thus creates good employment opportunities. The cost of establishing the processing units can be allayed by the installation of one or two units by progressive farmers. Small farmers can thus utilize the services of the units on a hire basis.

For the establishment of economically viable jaggery production units in the villages (Table 3), large-scale cultivation of sweet sorghum is essential, but that poses two major problems: the uneven maturity of the crop and the short harvesting period. In addition to these two basic problems, high grain-yielding sorghum is the major competitor of this crop. Our studies have indicated that different hybrid combinations of sweet sorghum have more uniform maturity (Table 4). This may help to solve the problem of uneven maturity. It was also found that these hybrids were photothermoinsensitive (Table 1). Regarding the short harvesting period, recent experiments and our observations indicate that the crop can be processed for jaggery production up to 1 month after physiological grain maturity. However, this slightly reduced the recovery percentage (Table 5).

Table 3. General yield level of jaggery.

1. Sweet sorghum stalk yield: 40 t ha^{-1}.
2. 1 t sweet sorghum stalks yield: 400 L juice.
3. 400 L juice yield: 60-72 kg jaggery.

40 × 60 kg = 2400 kg jaggery ha^{-1} $season^{-1}$ is possible. The acceptable market grain quality available is 1500 kg ha^{-1} $season^{-1}$ when stalks are harvested at or after grain maturity.

Table 4. Variation in number of days between first flowering to 50% flowering in some sweet sorghum hybrids and inbred lines.

	Season		
Entry	Winter 86/87	Monsoon 86	Winter 87/88
Hybrid-1	7.0	3.5	6.0
Hybrid-2	8.0	5.5	7.5
Hybrid-13	6.0	3.0	8.0
Hybrid-20	6.5	4.0	7.0
Hybrid-23	9.5	4.0	8.0
NSS-1	10.0	7.0	11.0
NR-15	15.0	13.0	17.0
N-53	9.5	9.0	9.0
NR-23	10.0	7.0	8.0

Table 5. Effect of harvesting stage on jaggery production from sweet sorghum hybrid NSSH-2, monsoon season 1987.

Treatment	Brix	Purity	Jaggery recovery from juice
1. Harvesting at grain maturity	16.0	87.4	17.5
2. Harvesting at 15 d after grain maturity	15.5	83.0	16.0
3. Harvesting at 30 d after grain maturity	14.0	69.8	13.5

Recent policy of the Government of Maharashtra regarding the distribution of canal water is based on the 8-month irrigation system. In this system, canal water is unavailable during the summer season (i.e., March to June for sugarcane plantations). Under such circumstances, the growing of sugarcane, which needs year-round irrigation, is becoming difficult, and due to this policy sugarcane yields will be reduced. This will ultimately affect the existing sugar industry of Maharashtra. Sweet sorghum could become a complementary crop to these industries. It has already been reported by Chatterjee et al. (1975) that even white sugar can be produced from sweet sorghum grown under Indian conditions. About 50 ha sweet sorghum are needed per day for each sugar factory. This large-scale cultivation of sweet sorghum will be possible if Government assures the farmers of prices and factory acceptance. Similar problems were faced by the existing sugar factories in India during their initial phases of establishment. It is logical to assume that the problems overcome by sugarcane factories can be similarly overcome by sweet sorghum sugar industries.

In India, *khandsari* units manufacture sugar from cane juice on a small scale. They have a crushing capacity of 500–800 t day^{-1}. These units could also utilize sweet sorghum for production of sugar. We are consulting farmers and the *khandsari* sugar makers to evaluate the practical problems of processing sweet sorghum for sugar production. So far, we have been unsuccessful, but we are confident that the Government policy and sugar and grain prices will compel the people concerned to utilize this crop for sugar production in the near future.

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Laboratory Procedures for Evaluating Grain and Food Quality of Sorghum and Pearl Millet: Problems and Prospects

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Abstract

To understand the processing and food quality characteristics of sorghum and pearl millet and to improve their utilization, standard laboratory tests are essential, and they are useful in screening breeders' samples. Discussed herein are methods currently available for evaluating various grain characteristics tha. influence food quality. Problems faced in laboratory evaluation procedures are also discussed, as are area~ for further research. A comparison of the laboratory method of dehulling with batch dehulling may lead to the identification of a suitable screening method. There is a need to conduct village-level surveys in African countries to better understand the utilization of sorghum and pearl millet. It is important to conduct taste evaluations in regions where these grains are consumed. Suggestions for increased utilization, including possible alternative uses, are included.

Introduction

Sorghum and pearl millet will continue to be used for traditional foods in the semi-arid tropics of Africa and Asia, although maize and wheat may replace thei. ,artially. Local cultivars are usually preferred over high-yielding varieties and hybrids. The preference for local cultivars is due to their good processing characteristics, acceptable quality, and storability as prepared food. Several grain factors are genetically controlled and the breeder can thus effectively manipulate the grain types to suit various end-use qualities.

Information on traditional food uses of sorghum and pearl millet is available (Rooney et al. 1987, Hoseney et al. 1981, Subramanian and Jambunathan 1980). Food quality includes grain quality, processing quality, and culinary quality. Grain quality standards such as moisture, protein content, and flour/grain grades are available for wheat and rice. But such standards are lacking for sorghum and pearl millet because they do not play a significant role in international market systems. Government pricing policies are important from the consumer's point of view because sorghum is costlier than wheat or rice in some developing countries. Since sorghum and pearl millet are important cereals in Africa and Asia, there is an urgent need to establish standards and techniques to characterize their grain quality by breeders, traders, and policymakers. In this report we discuss our experience, current status, and existing problems in evaluating sorghum and pearl millet cultivars in India for foods like *roti*, boiled sorghum, and porridges. The scope and need for further improvement and research to develop laboratory evaluation procedures for processing and food quality, which will be useful in sorghum and pearl millet programs, are indicated.

Grain Characteristics

Physical grain characteristics that contribute to food quality are color, endosperm texture, presence or absence of testa, and hardness, in addition to various

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Table 1. Tests for routine evaluation of sorghum and pearl millet grains and future research needs.

Factors/tests	Availability of methods	Future research needs	Reference
Grain color	A	NR	Murty et al. 1982
Endosperm texture			
Sorghum	A	NR	Rooney & Murty 1982
Pearl millet	NA	R	
Floaters test	A	NR	Hallgren & Murty 1983
Pericarp thickness	NA	R	—
Germ: endosperm ratio	NA	R	—
Kiya grain hardness test	A	NR	Subramanian et al. 1987
Grain size distribution	A	NR	—
Kernel shape	NA	R	—
Dehulling quality	A	NR	Reichert & Youngs 1976
Particle size index	A	NR	Subramanian et al. 1987
Water absorption grain and flour at 90°C	A	NR	—
Gel spreading test	A	R	Murty et al. 1982

A = Available, NA = Not available, R = Required, NR = Not required.

chemical characteristics. These physical characteristics influence both primary and secondary processing of grains for food. Each food product requires unique grain structure and composition.

Tests for routine evaluation of physical grain characters are listed in Table 1. Local preferences for grain color exist in various regions. White sorghum and pearl millet grains have good potential for bakery products. Sorghum grains are generally uniform in size, although in pearl millet, grain size varies considerably and we have encountered at least six different sizes of pearl millet within the same cultivar. Smaller grains generally have higher bran:endosperm ratios, which is unfavorable for dehulling recovery. Large, uniform, and round grains with hard texture are best suited for optimum dehulling recovery.

Subjective scoring of endosperm for texture (corneous/floury) is well established for sorghum, but not yet for pearl millet. Though corneousness has been used to evaluate grain hardness, this is not a precise technique for comparing cultivars. Grain hardness is still a very difficult parameter to measure and the available methods to determine it require further improvement.

Grain Processing

Dehulling

Dehulling of sorghum or pearl millet grains is a priority problem in many African countries. Mechanical dehulling reduces drudgery in food preparations while rendering the food more palatable and acceptable. Laboratory evaluation showed variation for dehulled grain recovery among sorghums and millets (Reichert and Youngs 1976). The Scott Barley Pearler and Tangential Abrasive Dehulling Device (TADD) have been used successfully for evaluating dehulling quality. Our studies indicate that these two systems of grain recovery are similar. There is a need to compare laboratory evaluation methods with those of batch-type commercial dehullers. Acceptable dehulled grain recovery and a larger proportion of nutrient retention in dehulled grain are desirable when grains are dehulled. Variation in loss of nutrients due to dehulling methods has been reported (Reichert and Youngs 1977). Therefore, a trade-off is needed between nutrient loss and dehulling.

Milling

Grinding grains to a desirable particle size is necessary to utilize the grains for specific foods, and is mostly done by hand pounding. Although the particle size may be manipulated to some extent by grinding or pounding, genotypic variation has been observed. Mechanical production of coarse (*brise*) and fine (*sanxal*) grits has been standardized by the Institut de technologie alimentaire, Senegal, and is being popularized. Laboratory methods are needed to test the cultivars for the production of grits or flour with desirable particle size suitable for the preparation of specific traditional foods. Sorghum and pearl millet cultivars that yield higher proportions of fine flour particles with less starch damage are better suited for bakery products than those with large flour particles and extensive starch damage. Factors like hardness and corneousness of grain play vital roles in the yield of grits/flour particles. It is desirable to subject all advanced entries to a milling test.

Secondary Grain Processing Methods

Secondary processing of grains or flour includes fermentation, malting, extrusion, flaking, and popping. Partial fermentation of pearl millet grain is common for the preparation of *hourou* in Niger. Sorghum flour is fermented before making *kisra* (Sudan) or *injera* (Ethiopia). Preliminary studies in our laboratory indicated that flours of hybrid and local sorghums differ in their fermentation characteristics as determined by swelling volume of the batter.

Malting is used to produce baby food and beer. Malting involves steeping the grain in water, followed by sprouting for up to 96 h. The ability to produce amylases on germination has always been the most important criterion (Novelle 1982). Malter grain is dried at 50°C to reduce the diastase activity. This process has been reported to improve storability and flavor and color of malt. The processing method used during malting significantly influences the diastatic power, and studies are needed to establish whether malted grain (green malt) can be used directly for making fermented porridges/beer without drying. Pearl millet malts are comparable to barley malt in amylolytic and proteolytic activities (Pal et al. 1976), and this similarity needs further exploration.

The possibilities of snack foods from sorghum and millets are excellent, since such products have long shelf life. Flakes made from sorghum generally have poor color, however, and improvement studies are needed to ensure consumer acceptability. Small sorghum grains with white or creamy color, medium-thick pericarp, and hard corneous endosperm are characteristics of popping types. Extruded fat-fried products are commonly produced from rice and wheat flour. Extrusion cooking has good potential for industrial utilization for sorghum and pearl millet.

Food Quality

From the breeder's viewpoint, grain types with desirable agronomic traits and good food quality must be further developed. Each type of food product requires different grain quality criteria. For example, soft wheat with low protein is desirable for cakes and cookies, and hard wheat with high protein is suitable for breadmaking. The International Symposium on Sorghum Grain Quality held at ICRISAT generated valuable information for the classification of traditional sorghum foods and for the identification of various physicochemical grain factors contributing to food quality (Rooney and Murty 1982). A survey conducted in 171 villages in India provided information on various foods prepared from sorghum and pearl millet and their quality criteria (Subramanian and Jambunathan 1980). Similar surveys at village level in Africa and Latin America will be very useful in understanding the requirements of the traditional consumers, the farmers.

Physical Chemical Characters

Food quality is complex and single tests can seldom predict overall food quality. The details of various tests are given in Table 2. It may be observed that the correlation between the quality parameters and physicochemical properties are not always high. It is obvious that several factors complement each other to influence food quality. After two decades of intensive research on wheat chemistry and quality, the microbaking test is still considered the best method of predicting bread quality. However, Finney et al. (1987) reported the use of six important milling and baking parameters to rank soft wheat cultivars for use in food. A value for each of the six quality parameters was assigned and the sum of total values was used for comparison of cultivars. Such a system should be developed for sorghum and millets. Correlations between several characters were worked out in evaluating sorghum and pearl millet foods, but further work is needed to understand the relationships among the characteristics to devise a suitable technique for screening. Rheology and texture measurements of sorghum and pearl millet foods are complicated. Instruments like Instron are precise but very expensive, and further work on standardization is required for sorghum and pearl millet foods. Attempts are needed to study the relationship between Instron values and taste panel results for evaluating food texture.

It is essential that breeders incorporate grain traits for preferred food quality along with agronomic factors contributing to yield. As a routine practice, specific tests as listed in Table 3 should be performed on all breeding lines. Although this list is not exhaustive,

Table 2. Relationship between physicochemical properties and overall food quality of sorghum and pearl millet.

Factors	r value/relationship	Reference
Dough		
Sorghum dough-rolling quality vs floaters (%)	-0.71[1]	Hallgren & Murty 1983
Good quality sorghum dough	Lower gelatinization temperature; higher peak viscosity and set-back values	Desikachar & Chandrashekar 1982
Roti		
Overall sorghum *roti*		Murty et al. 1982
vs water quality absorption (%)	-0.80[1]	
vs gel spread	-0.76[1]	Murty et al. 1982
vs amylose (%)	0.65[1]	Murty & House 1987
Good sorghum *roti* quality	Water-soluble flour fraction, water-soluble protein, amylose	Subramanian & Jambunathan 1987
Sorghum *roti* texture vs starch damage	-0.72[1]	Subramanian & Jambunathan 1987
Pearl millet *roti* quality		
vs swelling capacity of flour	0.81[1]	Subramanian et al. 1987
vs water-soluble flour fraction	-0.87[1]	Subramanian et al. 1987
vs water-soluble protein	0.67[1]	Subramanian et al. 1987
Tortilla		
Sorghum tortilla quality		
vs phenols	-0.50[1]	Murty & House 1980
vs gel spread	-0.66[1]	Murty et al. 1982
To (ugali)		
Sorghum *to* quality		
vs water-soluble amylose	0.58[1]	Murty & House 1980
vs starch granule number	-0.59	Murty & House 1980
Sorghum *ugali* quality vs gel spread	-0.80	Murty et al. 1982
Sorghum porridge quality vs starch damage	-0.85[1]	Subramanian et al. 1987
Good quality sorghum *muddhae*	High gelatinization temperature, low peak viscosity and set-back values	Desikachar & Chandrashekar 1982
Atole	Starch content, gelatinization and dextrinization of starch	Rooney et al. 1987
***Soru* (boiled product)**		
Sorghum *soru* quality score of vs swelling power of starch at 60°C	-0.67[1]	Subramanian & Jambunathan 1987
Pearl millet *soru* quality vs swelling of score starch at 70°C	-0.83[1]	Subramanian & Jambunathan 1987
Soru quality score vs gruel solids	-0.65[2]	Subramanian & Jambunathan 1987
Kisra		
Sorghum *kisra* quality vs gel spread	0.60[1]	Murty & House 1980
Cous cous		
Sorghum *cous cous* yield vs overs	-0.63	Galiba et al. 1985
Sorghum Bread		
Organoleptic evaluation vs evaluation (%)	-0.52[1]	Miller & Burns 1970
Organoleptic evaluation vs amylose (%)	-0.50[1]	Miller & Burns 1970

1. Significant at 5% level.
2. Significant at 1% level.

Table 3. Useful laboratory tests for evaluating processing and end-use properties of sorghum and pearl millet.

Traits	Food Products											
	Roti	*Torti-lla*	*Kisra/ injera*	Bread	Cook-ies	*To/ Ugali*	*Oji/ rouye*	*Nifro/ soru*	*Cous-cous*	Sun-dried snacks	Opaque beer	Starch
Tests for grain processing												
Dehulling recovery	3	3	1	1	1	1	1	1	1	1	3	2
Pericarp thickness	3	3	1	1	1	1	1	1	1	1	3	2
Grain hardness	1	1	2	2	2	2	2	2	3			
Prolamin content	3	3	2	2	2	3	3	3	3	3	2	2
TADD test	3	3	2	3	3	1	1	1	1	1	3	3
Milling recovery	1	2	1	1	1	1	1	3	1	1	2	1
Grain hardness	3	3	2	1	1	1	2	2	1	1	2	2
Flour particle size index	1	1	1	1	1	1	1	3	1	1	2	3
Malting/brewing/ fermentation	3	3	1	1	3	3	3	3	1	3	1	3
Prolamin content	3	3	1	2	3	3	3	3	2	3	1	2
Gelatinization temp. of starch	3	3	3	3	3	1	1	3	3	3	1	1
Pericarp thickness	3	3	2	2	2	1	1	1	1	1	1	2
Endosperm texture	1	2	1	2	3	1	1	1	2	2	1	2
Alpha-amino nitrogen	3	3	3	3	3	3	3	3	3	3	1	3
Tannin	3	3	1	1	1	2	2	1	1	1	1	1
Test for foods												
	1	1	1	1	1	1	1	1	1	1	1	2
Water retention capacity												
Flour swelling capacity	1	3	1	1	1	1	1	3	3	1	2	3
Alkali test (phenols)	1	1	1	1	1	1	1	1	1	1	2	1
Flour particle size	1	3	1	1	1	1	1	3	1	1	2	3
Gel spreading test	1	1	1	2	2	1	1	3	2	2	2	3
Volume changes in batter/ flour granulation	3	3	1	3	3	3	3	3	1	3	3	3
Protein	2	2	2	1	1	2	1	2	2	2	1	1
Water soluble flour fraction	1	2	3	3	3	3	3	3	3	3	3	3
Water soluble protein	1	2	3	3	3	3	3	3	3	3	3	3
Starch damage	1	1	2	1	1	1	1	3	3	2	2	1
Swelling power and solubility of starch	2	2	1	1	1	1	2	1	2	1	2	1
Amylose	1	1	1	2	3	1	1	1	2	1	2	1
Maltose	3	3	3	3	3	3	3	3	3	3	1	3
Visamylographic properties	1	1	1	2	2	1	1	1	2	1	2	1

1 = Important, useful to carry out the test.
2 = Important, further research needed for developing the test.
3 = May not be important; data not available.
TADD = Tangential Abrasive Dehulling Device.

these tests will be useful for evaluating the various food products to fix quality criteria which can be used for developing rapid, simple tests in a breeding program.

Taste Panels and Consumer Preference

Taste panelists must be familiar with the foods they are asked to evaluate. We have encountered difficulties in training panelists at Patancheru (India) because they were unfamiliar with pearl millet *roti*. Pearl millet *rotis* were therefore evaluated at Hisar (India), a major pearl millet-consuming area. Correlation between evaluations at Hisar and Patancheru varied between 0.12 and 0.53 for the various *roti* quality parameters studied. It is best to test the food in locations with the assistance of food research institutes or local universities/institutions where it is commonly consumed.

Consumer panels are different from taste panels. Before a variety or hybrid is released, it should be tested for acceptance as food at the village level by local consumers. Unless the new cultivar is equal or better in quality than the local cultivar, it will not be accepted, even though it may have other favorable attributes such as resistance to diseases and excellent yields.

Sorghum for Starch

Sorghum and maize starches are similar in several of their physicochemical characteristics. Starch properties of sorghum hybrids and high-yielding varieties must be compared with maize in terms of grain properties suitable to industrial starch production. Bold grains with low protein are preferred in the starch industry. Special attention should be paid to developing sorghum cultivars that yield larger amounts of starch as well as better quality starch.

Grain Sampling

A wide variation was observed in the organoleptic properties of *roti* made from grains grown in rainy and postrainy seasons (Murty et al. 1982). Measuring alpha-amylase activity in grains from the rainy-season crop may be useful because it influences food quality. The question arises whether cultivars growing in one location, for example in India, can represent the grains of the same genotype in another location, like Kenya. Therefore, a suitable system needs to be developed to represent the region and the type of food in question. A sample size of 100 g is required for testing physicochemical characters. For comparisons of dehulling quality or organoleptic evaluation, grain quantities of up to 1 kg are needed.

International Testing of Laboratory Methodology

Cooperative tests on cooking properties and amylography of rice were useful in comparing values across different laboratories (Juliano 1985). Collaborative tests for estimating factors like grain hardness, amylography, starch damage, in vitro protein digestibility, and food characteristics can be considered by different world laboratories working on sorghum and pearl millet. Cooperative testing will be useful in relating food quality factors with grain characteristics, including functional quality, and facilitate comparative evaluation across different laboratories, thus improving and defining methodologies.

Strategies for the Nineties

Exploratory laboratory research on the potential utilization of sorghum and pearl millet to assist the breeders and consumers is required. Efforts to identify major quality criteria of foods should continue, taking into account the traditional processes involved. Economically feasible milling technologies to suit the village-level consumer should be developed. Certain important areas for the future research are as follows.

- Basic breeding work on heritability of grain factors relating to milling, particle size distribution, and food quality.
- Starch-protein interaction, gelatinization characters, food rheology, and texture.
- Storage quality of flour and foods.
- Utilization of high protein, high lysine lines for developing baby foods and protein digestibility.
- Identification of bird-resistant high-tannin sorghum with hard grain to withstand dehulling.
- Grain quality standards for industrial uses: for example, starch, malting, brewing, and baking.

Summary and Conclusions

Laboratory evaluation of grains for food quality must form an integral part of any crop breeding program.

There is an immediate need to develop suitable processing technologies for sorghum and pearl millet to enhance consumer acceptability and develop alternative uses. Basic studies on physicochemical properties of the grain that relate to food quality are important and useful.

While developing high-yielding lines, breeders must incorporate traits essential in acceptable traditional foods, good processing qualities, or industrial products. Multidisciplinary research teams involving plant breeders, food technologists, cereal chemists, socioeconomists, home economists, and industrialists are necessary to achieve these goals.

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Quality Criteria for Opaque Beer in Zimbabwe

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Abstract

Sorghum and millets form a group of versatile and valuable brewing materials for the opaque beer industry in Zimbabwe. In this paper, we discuss the quality criteria for sorghum and millets and the four main purposes they serve in brewing. The first is the role they play as alternative starch-based adjuncts. The sorghum varieties currently grown in Zimbabwe are high in polyphenols, however, which limits the use of sorghum as an adjunct. The second and principal use of sorghum and millets is as a source of malt proteolytic and amylolytic enzymes. We assess malt quality on the following key parameters: moisture, sorghum diastatic units, solubility, extract, free amino-nitrogen, and soluble nitrogen. While large stocks of good quality malting grain are available at major depots of the Grain Marketing Board, the maltster currently has no choice in the quality of grain he receives for malting. This results in variation of malt quality. Recommendations are made on obtaining good quality grain for malting. Third, sorghum and millet malts are sources of lactobacilli and nutrients required for natural souring (lactic acid fermentation). Fourth, sorghum and millets give opaque beer desirable taste and color characteristics.

Introduction

Traditional or opaque beer is a popular beverage in southern Africa. The main characteristics of the product are a short shelf life of about 1 week, alcohol content acidity (lactic acid), suspended solids, and taste and color. The product is consumed in a continuously fermenting state. The manufacture of opaque beer (sorghum beer) in South Africa is well documented (Novelle 1981). Sorghum and millets form a group of versatile and valuable brewing materials for the opaque beer industry in Zimbabwe. In this paper, we discuss the quality criteria for sorghum and millets and the four main purposes they serve in brewing. We also propose approaches to meeting the quality criteria where they are currently unsatisfied.

Quality Criteria for Sorghum and Millets as Adjuncts

As alternative brewing adjuncts, sorghum and millets can compete with maize in nutritional composition and cost. The typical composition of the cereals is given in Table 1.

While sorghum and millets are only marginally lower in extract than maize, they have a nutritional advantage in protein and essential amino acids. The major red sorghum varieties grown commercially in Zimbabwe are DC 75 and DC 99 which contain about 1% polyphenols by weight of whole seed expressed as tannic acid. Other well-known red sorghum varieties include Red Swazi and Framida. Polyphenols

Table 1. Typical composition of maize, sorghum, and millets (percentage of mass of whole seed).

	Maize	Sorghum/millets
Moisture	9.0-11.5	9.0-11.5
Extract (carbohydrate)	70-72	65-68
Protein	8-10	9-13
Fat/oil	3.5-4.0	3.5-3.7
Polyphenols[1]	-	ca 1 (red sorghum)

1. Expressed as tannic acid.

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Chitsika, J.M., and **Mudimbu, M.W.** 1992. Quality criteria for opaque beer in Zimbabwe. Pages 151–155 *in* Utilization of sorghum and millets (Gomez, M.I., House, L.R., Rooney, L.W., and Dendy, D.A.V., eds.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

are condensed tannins responsible for the red pigmentation in mature sorghum grains. Polyphenols protect the seed against insect attack (Woodhead et al. 1980); bird attack; preharvest germination (Harris and Burns 1970); and fungal, bacterial, and viral diseases (Friend 1981). The chemistry of sorghum polyphenols and their effects on sorghum quality is reported in depth by Butler (1981).

While polyphenol content has important agronomic advantages for sorghum producers in terms of yield, it is a major limiting factor in the general use of red sorghum as an adjunct. High inputs of red sorghum meal in opaque beer brewing impart an excessive pinkish-brown color and an astringent taste and may lead to consumer rejection. Perhaps dehulling and novel techniques such as semi-wet milling can be used to remove pericarp and produce white flour from red sorghum, but the additional processing cost is prohibitive. Currently, the producer price for maize is Zimbabwean dollars (Z$) 180 t^{-1} and Z$ 100 t^{-1} for white and red sorghum. User prices are Z$ 222 t^{-1} for maize and Z$ 282 t^{-1} for both white and red sorghum. The Grain Marketing Board (GMB) buys grain from farmers at producer prices and sells it at prices which include GMB handling and storage costs. It is evident that the current purchaser price for sorghum is already higher than that of maize. In order to promote the utilization of sorghum and millets as sources of white flour (meal), a price competitive with maize is needed.

Quality Criteria for Malting Sorghum and Millet

The prime requirement of any brewery is to receive and use malt of high quality and consistency. Daiber (1978 and 1980) carried out extensive studies on the selection of sorghum varieties for malting. Daiber found that the quality of sorghum grain for malting was dependent on the genetic factors (e.g., variety), environmental factors (e.g., soil quality and fertilizer application), and seasonal factors (e.g., timing of rainfall and drought periods). There was an increase in protein content of sorghum with increased applications of nitrogen-based fertilizers. There was also a direct relationship between protein content and sorghum diastatic units (SDUs). We have recently completed an evaluation of 20 new sorghum varieties for malting potential and identified stocks of sorghum of established varieties at various depots of the GMB. We observed that sorghum grain for malting has protein levels around or greater than 9%. In addition, the grain must have high germinability (95-100%) and viability. After all, germination of viable grains triggers the commencement of enzyme development during malting. Factors affecting germinability and viability are conditioned by periods of storage and grain maturity. Uniformity of grain facilitates good control of the malting process. There is no doubt that the best criterion for selecting sorghum grain for malting is its potential to produce high diastatic power (greater than 25 SDU).

The current practice in Zimbabwe is that the GMB stacks bags of different sorghum varieties from different farmers together. The grain purchased from communal farmers is frequently from mixed or unknown varieties. This practice results in deliveries of grain of inconsistent quality to the maltster, leading to variable malt quality. Since the potential to produce high diastatic power is dependent on the genetic properties of the variety (Daiber 1978), we recommend that the GMB stack sorghum for malting by varieties, and that only varieties of superior malting quality should be supplied to the maltster. One approach to achieving this would be for the GMB to restrict intake of specific varieties at specified depots from which supplies to the maltster would be withdrawn. Mixed or unknown varieties would be separated and used for purposes other than malting. Another suggestion is to introduce restrictive arrangements of contractual production of selected varieties between farmers and the maltster. The development of potentially better varieties is encouraged. To this end, Chibuku Breweries liaises closely with sorghum and millet breeders at the Department of Research and Specialist Services of Zimbabwe's Ministry of Lands, Agriculture, and Rural Resettlement.

Let us now turn to the current quality of malt used by Chibuku Breweries. A summary of results is illustrated in Table 2. National Foods Limited, Zimbabwe, malt the sorghum and millets for Chibuku Breweries as part of an agreement between the two companies. Batches of malt with low SDU and/or low solubilities tend to give low (poor) diastatic activity, low free alpha-amino nitrogen (FAN) (alpha amino-acids), and low total soluble nitrogen. When such batches are used for conversion in brewing, the resulting wort has poor fermentability. SDU is comprised of alpha and beta amylases which degrade starch to dextrins and fermentable sugars. FAN in wort is preferentially used to provide nitrogen to the yeast cells for growth. Pickerell (1986) examined the influence of various wort FAN levels and their interactions with wort sugars during sorghum beer fermentations. His work

Table 2. Quality of sorghum malt used by Chibuku Breweries Division, 1987.

No. of Month	Moisture batches	SDU (%)	Soiubility (%)	Activity (%)	Extract (%)	FAN (%)	Soluble (ppm)	N
Jul	9 range	4.1-7.6	7-31	56-92	6.0-26.7	52.9-64.6	85-333	0.026-0.053
	Average	5.6	21	82	17.2	59.3	167	0.037
Aug	11 range	3.6-6.9	17-39	48-95	10.1-34.0	53.6-66.9	117-187	0.036-0.060
	Average	5.2 27	79	21.1	60.1	151	0.046	
Sep	9 range	5.1-7.5	10-32	63-97	8.0-29.0	39.7-65.9	96-239	0.030-0.060
	Average	6.1	22	83	18.0	55.4	153	0.043
Oct	10 range	4.3-7.2	25-40	34-98	11.0-39.0	62.3-68.8	146-204	0.035-057
	Average	5.8	33 76	25.0	65.0	171	0.049	
Nov	10 range	3.4-7.0	18-40	67-97	12.1-32.4	53.3-71.1	110-160	0.033-0.047
	Average	6.7 27	79	21.3	62.5	142	0.040	
Dec	11 range	4.6-8.7	18-35	63-100	14.5-29.8	56.7-66.1	125-250	0.040-0.050
	Average	6.6	26 81	21.1	60.9	160	0.047	
Specifications		5-7	22-23	75	16.5	40	150	0.05

SDU = Sorghum diastatic units.
FAN = Free alpha-amino nitrogen.

showed that at the same sugar level, high FAN worts promoted faster fermentation of the available sugars than did low FAN worts.

Our experience indicates that the general ranking in malt performance on a given starch substrate is related to diastatic activity (SDU × solubility) of each malt. The higher the diastatic activity, the better the malt performance. The results in Table 2 show a wide range in the quality of malt produced. On many occasions, we found that the inconsistent quality and mixture of varieties of sorghum grain delivered to the maltster are related to the variable quality of malt produced.

Sorghum and millet malts are sources of lactobacilli and essential nutrients required for natural souring (lactic acid fermentation). Sorghum and millet malts are widely used in the fermentation of alcoholic and nonalcoholic beverages (Novelle 1981). We are currently screening and identifying the microbiological flora in sorghum and millet malts.

In November 1987 visits were made to major GMB depots to identify the stocks of sorghum grain and evaluate the malting potential of that stock. The stocks of sorghum grain were of good quality (Table 3). Chibuku Breweries, which uses about 10 000 t sorghum a year, is the largest user of sorghum in the country. Present stocks of sorghum grain of good quality are enough to meet the company's utilization requirements for more than 4 years. However, the longer the storage period, the greater the risk of deterioration of grain quality due to infestation and protein loss. The GMB should therefore supply sorghum grain of good malting quality to the maltster. Large-scale sorghum farmers are capable of supplying grain of consistent quality. In order to reduce the grain surplus, alternative uses of sorghum should be developed. A favorable pricing policy would no doubt encourage further grain utilization.

Table 3. Stocks of sorghum grain of good quality.

GMB depot	Intake[1] (t) 1985/86	Intake[1] (t) 1986/87	Total (t)
Chegutu	2 618	25 334	27 952
Kadoma	3 488	5 628	9 116
Norton	371	3 038	3 409
Concession	213	2 225	2 438
Bindura	418	2 051	2 469
Banket	750	1 500	2 250
Total (tons)	7 858	39 776	47 634

1. Intake year: Mar to Feb of following year.

Table 4. Quality of micromalted sorghum.

Sample	GMB depot	Variety No.	Intake (%)	Stack	Moisture	SDU (%)	Solubility ratio	Alpha/beta amylase (%)	Extract (ppm)	FAN (%)	Total N (%)	Total sol. N (%)	Total sol. N / Total N
A	Chegutu	DC 99	86/87	7	7.7	59	96	2.3:1	65.4	184	1.29	0.067	5.2
B	Chegutu	DC 99	86/87	7	6.6	48	96	2.9:1	69.7	192	1.27	0.089	7.0
C	Kadoma	DC 99	87/88	10	6.8	45	94	2.4:1	69.8	176	1.50	0.084	5.6
D	Kodoma	DC 99	87/88	1	6.5	45	83	2.4:1	68.7	194	1.54	0.082	5.3
E	Kodoma	DC 99	86/87	7	7.2	35	98	3.1:1	57.7	220	1.35	0.070	5.2
F	Banket	DC 75	86/87	10	7.8	47	96	2.4:1	64.2	128	1.40	0.069	5.2
G	Concession	DC 75	86/87	13	7.6	49	96	2.2:1	64.2	176	1.33	0.071	5.3
H	Bindura	DC 75	86/87	1	8.4	31	94	1.8:1	57.7	153	1.61	0.077	4.8
I	Bindura	DC 75	86/87	4	8.5	48	95	2.7:1	58.5	176	1.56	0.082	5.3
J	Banket	White sorghum	-	-	8.1	48	85	2.0:1	72.8	162	2.01	0.079	3.9
Standard specification								5-7	22-33	75	40	150	>0.05

The quality of micromalted sorghum from various GMB depots is given in Table 4. Generally, the results on SDU, alpha/beta amylase ratio, extract, FAN, and total soluble nitrogen were high. It appears, therefore, that the micromalt was well modified. These results were higher than results from malts obtained under normal plant scale operations and reflect the conditions pertaining to the micromalting procedure used. It is interesting to note how well white sorghum performed in comparison to red sorghum. These results do not suggest that one sample is better than or preferable to another, but they do help to identify which sorghum grains have good malting potential. The overall result was that all the grain samples that were micromalted possessed good malting potential.

We have one important recommendation related to the evaluation of sorghum varieties for malting potential. The micromalting procedure is critical to achieving certain levels of diastatic activity. The method of analysis for SDU is secondary but still important. ICRISAT should organize a collaborative study to establish a standardized methodology for sorghum micromalting and analysis of SDU, whose methodology should be used for comparative evaluation of sorghum varieties for malting potential.

Conclusions and Recommendations

Sorghum and millets form a group of versatile and valuable materials for the brewing, food and stockfeed industries in Zimbabwe. A favorable pricing policy is advocated to promote the utilization of sorghum and millets as substitutes for maize. Good grain for malting should have high viability, 95-100% germinability, protein of 9% or more, and potential for high diastatic power (25% SDU). Since the potential to produce high diastatic power depends on the genetic properties of the variety, we recommend that the GMB stock sorghum grain for malting by variety, and only varieties of superior malting quality should be supplied to the maltster.

Another suggestion is to introduce contractual production of selected varieties between farmers and the maltsters. These restrictive arrangements would ensure the supply of grain of consistent quality to the maltster, who in turn would produce malt of high quality and consistency—the prime requirement of any brewery. The development of new varieties with better potential is encouraged. We also recommend an international collaborative study to establish a standardized methodology for sorghum micromalting and analysis of diastatic power. This methodology should be used for comparative evaluation of sorghum varieties for malting potential. Due to the lack of internationally standardized methodology, the SDU results from one laboratory cannot be reliably compared with those from another.

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Discussion

A.O. Koleoso: Is it preferable to pasturize opaque beer for longer shelf life?

J. Chitsika: Shelf life is about a week. It is felt that pasturization might change the characteristics of the local beer.

A Carney: Would malting and brewing not be another area where we could encourage something like contract farming to ensure the correct sort of grain quality?

J. Chitsika: I believe so. Barley in Zimbabwe is grown by farmers around Kewkwe who are contracted by the malster.

J.N. Mushonga: Concerning the mixture of grain, it seems that the grain grown by the farmer is already mixed genetically. So we are trying to separate the pure lines of a given variety.

A.B. Obilana: What is the name of the white variety from Banket you identified as good for malting?

A. Carney: It is difficult to be sure as it is merely stored as "white". But from seed sales it could be a mixture of SV1 or SV2.

M. Mudimbu: Mixing of grains is seen not only in mixed varieties of red swazi and framida due to impure strain, but in mixes of DC 75 with other varieties.

T. Rukini: Annual utilization by Chibuku is more than 10 000 t. Is this for malt or for both malt and adjunct? Is it not possible to increase sorghum utilization by using sorghum as an adjunct instead of maize?

J. Chitsika: The consumption figure provided includes both sorghum meal and sorghum malt. High sorghum meal inputs in opaque beer brewing impart an excessive pinkish-brown color and an astringent taste which are undesirable and may lead to consumer rejection of the product.

T. Rukini: Is it possible to define practical quality parameters to be adopted by the GMB?

J. Chitsika: Yes. Firstly, GMB should stack grain by variety to minimize mixing of varieties and grain from different farmers.

The Breeder's Role in Crop Utilization: A Perspective

D.S. Murty[1]

Abstract

Research advances during the last 10 years in sorghum utilization and food quality evaluation are briefly reviewed. Grain quality criteria useful in breeding for traditional processing and food quality are summarized. Selection of important plant and grain attributes related to utilization is illustrated. Endosperm texture, i.e., proportion of hard and soft endosperm, can be evaluated to reliably predict the potential use of sorghum grain in products. The need for overall improvement of sorghum grain for much wider domestic and industrial use is emphasized. The concepts of breeding for specific end-uses and total plant utilization for food, feed, fiber, and fuel are discussed. An integrated breeding scheme, aimed at improved utilization of sorghum, is presented. Finally, the need for collaborative and cooperative efforts between breeders, chemists, food technologists, engineers, and industrialists is emphasized.

Introduction

Sorghum is used as a staple food in Asia and Africa and as animal feed in the developed world. Sorghum grain is processed and consumed domestically following diverse traditional techniques. Unlike crops like wheat, industrial utilization of sorghum is limited. Therefore, crop quality standards have been either vague or absent. Plant breeding programs were concerned mostly with selection for higher yield. Selection and crossing within native collections of germplasm posed few problems related to consumer acceptance of the breeding products. However, increased use of temperate sorghums in the tropics and selection for early-maturing varieties and hybrids with improved harvest index brought forth the importance of quality in breeding programs.

During the last two decades, a great deal of progress has been made in the understanding of the genetics, structure, and physicochemical properties of sorghum grain (Hulse et al. 1980, Hoseney et al. 1981, and Rooney and Miller 1982). Collaborative efforts between scientists in national programs and the international programs of ICRISAT, IDRC, INTSORMIL, and other institutes have resulted in evolving a tentative list of major sorghum food categories and grain quality attributes associated with the respective categories (Rooney and Murty 1982a, 1982b). Research advances in sorghum utilization and nutrition have opened up wide avenues for sorghum breeders to interact with scientists of other disciplines and broaden their breeding perspectives. Apparently, the concept of breeding sorghums for specific end uses has just been established.

An attempt is made here to briefly review the research advances in sorghum food quality evaluation and to suggest broad approaches to breeding with specific reference to various end-uses of the crop.

Grain Quality Attributes Suitable for Traditional Foods

Processing quality

Eight major categories of traditional sorghum foods are recognized (Rooney and Murty 1982b).

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1. Unfermented breads
2. Fermented breads
3. Stiff porridges
4. Steam-cooked products
5. Boiled products
6. Snacks
7. Alcoholic beverages
8. Nonalcoholic beverages.

Rooney et al. (1986) summarized the traditional processing and cooking procedures used in their production. Several of these traditional foods are prepared from sorghum grain after hand decortication with a mortar and pestle, which reduces the coarseness and grittiness of the product. In Africa, mortar and pestle dehulling is a regular domestic feature and mechanical dehulling has been introduced into urban areas in only a few countries. High-yielding cultivars are therefore acceptable to the farmers only if their grain can be processed effectively by hand-decortication. Studies in Burkina Faso on grain samples from on-farm trails indicated that under low productivity conditions, an yield advantage of 25% over the local variety can be offset by 20% less endosperm recovery from the improved cultivar by traditional processing (ICRISAT West African Programs 1987).

It has been established that oval or round kernels with thick pericarp and highly corneous endosperm are ideal for traditional dehulling (Murty et al. 1984). Corneous grains give higher pearled endosperm recovery and produce fewer losses due to broken chunks. Soft endosperm types and those with testae exhibit the poorest dehulling quality. Turtle-shaped grains (caudatum race), even when they are corneous, pose problems in pericarp removal at the hylar region. Currently, sorghum breeders frequently use caudatum types in their crossing programs. Since turtle-shaped grain is governed by dominant genes (Schertz and Stephens 1966), appropriate selection pressure should be exercised in segregating populations in favor of symmetrical grains. Grain damage caused by molds, weathering, and headbugs significantly reduce dehulling quality (ICRISAT 1986, 1987). Selection for increased grain hardness and a symmetrical shape would greatly improve processing and storage quality. Breeders should evaluate traditional quality, storage quality, and traditional dehulling quality of the grain samples of their elite varieties harvested in the crop season under local conditions.

Food quality

With the exception of beverages, there is universal preference for white- and cream-colored products (Rooney and Murty 1982a). Although red- and brown-colored foods are acceptable in some regions for various reasons, white products are invariably preferred. In view of the deleterious nutritional effects of tannins, breeders should select for a colorless pericarp. If red and brown grains or products are desired, red grains free from testae should be selected. Decortication of grains with a thin red pericarp and intermediate endosperm texture results in attractive white products. Therefore, such grains can be used for food as well as beverages. White grains from tan-colored plants are known to produce few off-colors in the product. Color should preferably be evaluated by objective tests (Rooney and Murty 1982b).

Experience with several taste panels on various traditional foods has shown that the taste parameter is extremely difficult to establish with consistent results. There are no objective tests to measure taste. Frequently, taste responses are associated with responses for texture. Taste preferences were either in favor of or against products made from grains with testae (Rooney and Murty 1982a). When white grain types were tested, taste preferences were inconsistent or neutral. The conclusion is that if white grain types free from polyphenols are selected, consumer resistance is not expected.

Texture and storage quality

Texture and storage quality are the most critical food attributes. In general, response of taste panels and consumers is distinct and consistent for these two traits. Characteristics such as the tackiness of thick porridges and boiled products, the doughy quality and rolling quality of *roti* and *injera*, or gel consistency can be evaluated objectively, although standard tests are still under development and need to be improved.

Endosperm texture

Rooney et al. (1986) summarized the most desirable kernel characteristics of sorghum for use in various traditional foods. In general, the property of sorghum grain affecting quality of the food product most consistently is endosperm texture (proportion of hard to soft endosperm). Three classes of endosperm texture were identified: hard, intermediate, and soft. Hard endosperm texture is suitable for porridges, while intermediate texture is suitable for unfermented breads, boiled rice-like products, and beverages. Soft grains are best for fermented breads.

A considerable degree of genotype/environmental interaction affects endosperm texture (Murty et al. 1982a, ICRISAT 1985). It was also found that hardness is governed by partially dominant genes. Grain texture can be determined by a variety of simple techniques (Kirleis and Crosby 1982, Hallgren and Murty 1983).

Attributes of Industrial Use

Malting quality

Novelle (1985) discussed various quality attributes of grains that affect sorghum beer production. Grains possessing a bright red color (i.e., free from testae and tannins) are sold at premium prices. High diastase grain activity is the most desirable and important character for beer production. In view of the bright prospects for increased use of sorghum in the brewing industry, breeders should evaluate a wider range of germplasm and breeding lines for malting quality and examine the possibilities for genetic improvement.

Milling quality

Several novel food products can be made from sorghum by using decorticated sorghum grains. It is expected that mechanical dehulling will soon be popular. Therefore, milling quality (i.e., mechanical decortication and flourmaking) is an important grain quality attribute. Most of the comments made under traditional dehulling quality also apply to mechanical dehulling quality, except for pericarp thickness which may be either thin or thick. In this context, laboratory dehulling machines are very useful for evaluation of small quantities of breeders' samples (Reichert 1982). In general, in spite of differences due to the relative efficiency of milling techniques, hard grain with a symmetrical shape is the most desirable.

Reference has been made to the effects of molds and weathering on sorghum grain quality. Grain weathering damage is frequently restricted to the pericarp, and mechanical dehulling of such grain can still produce flour nearly as attractive as produced from normal grains. Grain hardness is associated with grain mold and weathering resistance (ICRISAT 1986, 1987). Therefore, breeders should consider evaluation for grain hardness and mechanical dehulling quality on a routine basis using laboratory machines.

Energy and biomass

Sweet sorghum syrup has been produced in the USA since colonial days (Freeman and Broadhead 1986). Schaffert and Gourley (1982) described stalk quality characters of several currently used syrup and sugar varieties of sorghum in Brazil and suggested the use of sorghum for alcohol (energy) production. Sorghums with desirable grain yield, sugar in the sap, and useful fiber are referred to as high-energy sorghums (Creelman et al. 1982). These sorghums are 1.5-2.5 m tall and yield about 5 t ha^{-1} of high quality grain suitable for human consumption, fermentation, or livestock feed. Their stalks have high carbohydrate levels and are suitable for multiple uses (food, feed, fiber, and fuel). Thus, sweet sorghum, grain sorghum, and high-energy sorghum represent a range of variability within the species *Sorghum bicolor* [L.] Moench. Sorghum is also recognized as the most efficient crop in terms of biomass production per day, surpassed only by napier grass (Loomis and Williams 1983). It was estimated in Texas, USA, that fresh biomass yields in excess of 60 t ha^{-1} and ethanol yields in excess of 5-6000 L ha^{-1} are possible with improved cultivars (Miller 1986). Therefore, the broad range of genetic variability available in sorghum should be exploited by breeders to customize sorghum varieties to suit the needs of industry.

At ICRISAT Center, several germplasm accessions were identified possessing sweet stalks (Prasada Rao and Murty 1982, Seetharama et al. 1987). Fifty early-maturing selections exhibiting more than 16 brix degrees were derived from crosses with selected germplasm accessions (e.g., IS 990 and IS 19674). Since sweet sorghum production is affected by the same biotic and abiotic factors that affect grain sorghum, it is important to evaluate such selections in the regions proposed for their cultivation.

Nutritional Factors

Protein quality

Although considerable variation exists among sorghum cultivars in amino acid composition, lysine and threonine are recognized as the most limiting essential amino acids (Hulse et al. 1980). The amino acid leucine has been found to be far in excess of the desired level. In view of the identification of sources of high lysine and an understanding of their breeding behavior, the prospects of breeding improved levels of lysine with an average protein content (10%) appear to be brighter (Axtell et al. 1982). However, it is recognized that genetic improvement of endosperm protein quality of sorghum is still a plant breeding research objective and not a routine plant breeding objective. Plant breeders should no doubt continue to select for an optimum grain protein content of 10%.

Inhibitors

The antinutritional effects of polyphenols (tannins) are well known. Because production of these inhibitors in sorghum grains is governed by the major genes B1, B2, and S, breeders can use this information to make quick progress in selecting for tannin-free grains (Rooney and Miller 1982).

Hulse et al. (1980) reported that phytate P in the grain may be another important antinutritional factor. Doherty et al. (1982) observed that varietal effects were the most critical in selecting a sorghum variety for human consumption containing optimum available phosphorous. However, more information is needed for breeders to follow up on this aspect.

Breeding Scheme

Plant breeders need to play a crucial role in creating and improving plant types for novel uses. It is necessary to accumulate genes from the best- known sources of the desired plant characters in the crossing block to enhance the chances of recombination of multiple traits. Widely divergent crosses may not yield the desired recombinants in a good agronomic background in the first attempt. In a conventional breeding program, in order to make desired level of progress, it might be necessary to recycle selected advanced generation progenies. Fortunately, in sorghum, plant color, pericarp color, presence of tannins, glume color, plant height, and maturity are all governed by major genes. Grain size, grain hardness, and juiciness of stalk are more heritable than characters like yield. Although precise physicochemical tests to predict sorghum food quality in early segregating generations are lacking, considerable progress can be made by selecting for appropriate endosperm texture, which is highly associated with the quality of specific food categories (Rooney et al. 1986).

In general, within each endosperm class (hard, intermediate, and soft), the preferred sorghum should have a white pericarp, tan plant color, straw-colored glumes, and no testae (except where a red pericarp is desirable, such as for traditional beer). An outline of a general breeding scheme aimed at improving multiple uses of sorghum is presented in Table 1.

Table 1. A general breeding scheme for improving multiple uses of sorghum.

Crossing block with sources of good grain quality, mold and weathering resistance, high stalk sugar, and other yield-limiting factors		
	F_1	Hybrids (single, three-way, and double crosses).
Crop season	F_2	Select for optimum grain size, absence of testae, colorless pericarp, round shape, appropriate endosperm texture, tan plant color, straw glume color, mold and weathering resistance, juicy stalks, and other agronomic characters in the field.
Crop season	F_3	Select for the desired grain characters, appropriate maturity, grain mold resistance, lodging resistance, high biomass, high brix value, high grain yield, and other agronomic characters in the field. Confirm grain texture and light color reaction for KOH in the laboratory.
Off season	F_4	Select for high brix value and other agronomic characters in the field. Evaluate grain hardness, milling quality, diastase activity, and optimum protein content with small samples of grain in the laboratory.
Crop season	F_5	Evaluate grain yield, biomass, and harvest index. Select for mold resistance and high brix value in the field. Conduct milling and other physicochemical tests for food quality in the laboratory (e.g., dough quality, gel consistency, flour particle size, protein content). Evaluate juice quality.
Off season	F_6	Carry out mini-product tests (for the desired food system) with the aid of taste panels. Conduct stalk and juice quality tests.
Crop season	F_7	Carry out multilocational yield tests. Evaluate selected entries through consumer tests.

Empirical selection for many desirable grain and stalk traits is possible in the F_2 generation. Experience indicates that in sorghum, segregation for several major genes continues until F_3. Therefore, selection within F_3 during the crop season should be profitable. Additional selection based on objective tests using small samples of grain could be carried out in the F_4 generation. In addition to grain yield tests, a battery of quality tests can be conducted using F_5 progeny harvests. It is desirable to conduct mini-product tests (e.g., micro-malting tests) in the F_6 generation, and advance selected lines to the F_7 generation for multilocational yield tests and consumer tests.

The breeding scheme presented here is only general and could be modified depending on the specific objectives of a breeding program within a region and the breeding system chosen. For example, in a population breeding scheme, after sufficiently random-mating the population, selection could be started in the S_1 generation in a similar method proposed for F_2 generation of a conventional breeding scheme and continued until the S_6 generation to obtain pure line varieties. In a breeding program where the objective is to improve a specific end use, the number of quality tests might be correspondingly reduced to speed up progress.

Collaboration

Some of the quality tests suggested in the last few sections need to be carried out by specialists (i.e., chemists and food technologists). Unless the screening technique is simple and rapid, breeders cannot carry it out routinely. For example, micromalting tests may have to be carried out in cooperation with breweries. Similarly, enzyme assays, specification of starch properties, and other sophisticated tests must be carried out in collaboration with chemists. It should be emphasized that improvement for multiple quality factors requires close collaboration between scientists of the various disciplines involved (i.e., breeding, biochemistry, physiology, pathology, food technology, etc.).

The principal job of a breeder is to assess the range of variation available for the desired trait and to determine its heritability. This can be followed up with appropriate selection and breeding procedures to improve the trait. Our knowledge of the physicochemical basis of the traditional foods is very limited and further research is required to suggest efficient, simple, and rapid physicochemical tests to predict specific food quality. Development of such techniques requires a close cooperation between breeders, chemists, food technologists, and engineers. Frequently, a novel technique or product is evaluated from grains of an arbitrarily chosen variety (e.g., a high-tannin variety) and its quality is rated good or poor. It might be possible to make better progress by choosing an appropriate range of varieties for such experiments in consultation with crop scientists. Breeders must respond to the needs of both consumer and industry. When a potential food product has been identified, breeders should focus their attention on the assessment of genetic variation for the desired trait or a correlated trait of the food product. For example, Murty et al. (1982b, 1984) screened a large number of germplasm and breeding lines and found superior genotypes for popped and boiled sorghum products.

Grain utilization is affected by supply, demand, industrial infrastructure, socioeconomic factors, and governmental policies relating to grain prices. Quality requirements are not static and may change over time. It is certain that alternate uses of sorghum will increase in the near future. Sorghum breeders can look forward to a more active and successful role in the improvement of sorghum and its utilization.

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Discussion

J.E. Cecil: Where is phytate P located?

D.S. Murty: It is located in the aleurone embryo and pericarp. Doherty et al. (1982) observed that dehulling did not reduce percentage of phytate P in the product.

J. Chitsika: There is a wide variation in maximum sorghum diastatic units (SDUs) reported for sorghum malt. Can I propose to this workshop the need to carry out an international collaborative study on methods of SDU determinations? In such a study, it would no doubt be imperative to use the same sorghum malt.

D.S. Murty: I welcome this idea. There is a need to standardize diastase activity determination procedures so that scientists can understand each other better.

M.I. Gomez: As an addendum to Dr Chitsika's suggestion, there should be a systematic standardization of terminologies and methodologies for evaluation of other quality parameters as well.

A. Carney: The free air flow appears to be critical to development of SDU. Enzyme stability seems to extend to 70°C or 80°C in dry grain.

V. Subramanian: Standard laboratory conditions like relative humidity, temperature, grain weight/volume, and size of bag for malting quality need to be standardized.

A. Carney: The micro-malting system is critical to SDU.

R.L. Rooney: The proceedings of the Sorghum Quality Symposium are available from ICRISAT. They contain significant information on sorghum characteristics, standard tests, and traditional and industrial sorghum processes and products of interest to sorghum users.

Feeds

Methods of Processing Sorghum for Livestock Feeds

L.W. Rooney[1]

Abstract

Sorghum without tannins has 95% of the feeding value of yellow dent maize for all livestock species in the USA. Sorghum for swine and poultry rations is usually ground in a hammermill. For poultry, the ration is pelleted and reduced to granules. For beef cattle in feedlots, where 85-90% of the ration is grain, sophisticated processes including reconstitution, early harvesting and high-moisture storage, steam flaking, popping, micronizing, and exploding are used to improve the feed efficiency by 10-15% over dry ground sorghum. Experience has shown that sorghum must be more vigorously processed than maize. It is important that the flakes of sorghum be very thin. This relates to the need to disrupt the peripheral endosperm cells to expose the starch to the digestive fluids. Sorghum hybrids differ in their response to processing. Some, especially waxy and yellow endosperm types, process more easily than others. Some feedlots pay a small premium for certain hybrids. In general, a white pericarp and a yellow, waxy endosperm are best. Brown sorghums with high tannins, compared to other sorghums, have decreased feed efficiency. Animals consume more grain to produce the same weight gains, thereby decreasing feed efficiency. Animals prefer nonbrown grains, but they consume high-tannin sorghum rations readily when they do not have any choice.

Processing Sorghum for Ruminant Feeds

Sorghum is fed to beef cattle in the sorghum belt of the USA. In Texas, Kansas, Oklahoma, and Nebraska, feedlots use properly processed sorghum for 80-90% of the ration. Some feedlots with 100 000 or more cattle require more than 150 t sorghum daily. The sorghum must be processed rigorously to obtain 95-100% the value of maize. This has led to several sophisticated processing methods (Riley 1984).

Steam flaking, popping, micronizing, reconstitution, and early harvesting and high moisture storage are methods presently used (Table 1) (Hale 1973). The most popular method for large lots is steam flaking because of its convenience and flexibility. The sorghum flake must be extremely thin to obtain optimum feed efficiency. Popping and micronizing produce the same results as steam flaking. These methods are effective because they thoroughly disrupt the cellular structure of the sorghum kernel to make the starch granules accessible to digestion. Protein digestibilities are slightly decreased by wet- and dry-heat processes while 50% of the starch is gelatinized.

Reconstitution (Pflugfelder et al. 1986) requires storage of large quantities of wet grain for 2-3 weeks which creates logistical and cash flow problems for large feedlots. However, it requires reduced equipment and energy for processing. Thus, reconstitution is used by smaller feedlots. The storage allows time for hydration and enzymatic hydrolysis of kernel components, which results in significant improvement in the protein digestibility of reconstituted ground sorghum. Many of these changes weaken the peripheral and corneous endosperm, which increases release of starch granules from the protein matrix when the wet

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Table 1. Common methods of processing sorghum for livestock feed used in the United States.

Category	Type of Process	Procedure	Characteristics
Mechanical action	Grinding	Particle size reduction using hammer, plate, or pin mills.	Most commonly used (least expensive). Increased feed efficiency and digestibility.
	Dry & steam rolling	Pass grain through roller mill with or without steam. Subjected to steam for only 2–3 min. Steam produces less fines.	Increased digestibility, similar to dry grinding.
Wet processing	Reconstitution	Increase grain moisture to 25–30%. Wet grain is anaerobically stored 2–3 weeks prior to grinding.	Improves feed efficiency about 15% over dry grain due to a higher protein and energy digestibility.
	Early harvest	Grain is harvested at 20–30% moisture and stored anaerobically or without organic acids, i.e., propionic.	Similar to reconstitution.
	Soaking	Soak grain in water for 12=24 h prior to rolling or grinding.	Tendency for grain to ferment or sour. Only limited use.
Heat and moisture	Steam rolling	Grain subjected to live steam 3–5 min, then rolled.	Slight increase over dry rolling.
	Steam flaking	Grain exposed to high moisture steam and equilibrated for 5–15 min to 18–20%. Then, grain is flated to desired flake thickness.	Sorghum requires longer steaming than corn. Thin maize flaking of sorghum increases digestibilityand feed efficiency.
	Pelleting	Ground grain is conditioned with steam, forced through a die, and pellets are colled.	Reduces dust and improves palatability, uniformity, and handling of feeds.
	Exploding	Grain exposed to high-pressure steam, the starch is gelatinized, the pressure is decreased, and rapid expansion of the kernal occurs.	Similar to puffing of cereals for breakfast foods. Feed efficiency is similar to steam-flaked grain.
Hot dry heat	Popping	Hot, dry air expansion of grain. Bulk density is low. Density is increased by spraying with water and occasional rolling.	Ruptures endosperm increasing starch availability. Feed efficiency is similar to steam flaking.
	Micronizing	Heat grain with gas-fired infrared burners to the point of eversion followed by rolling through a roller mill.	Feed efficiency similar to steam flaking, exploding, or popping. Bulk density similar to steam-flaked grain.

grain is ground. For early-harvested high-moisture grains, the protein matrix is not tightly bound to the starch because the endosperm is never allowed to dry. Thus, the starch granules are efficiently released from the protein during grinding.

Sorghum varieties affect the nutritional value significantly. Sorghums with condensed tannins (brown, bird-resistant) have significantly lower feed efficiency than sorghums without condensed tannins. In the literature these are often referred to as low-tannin types.

Contrary to commonly held misconception, animals consume greater quantities of brown high-tannin sorghums to produce about the same gains as animals fed sorghums without tannins. When given a choice, animals consume sorghums without tannins first. However, animals (including birds), will consume large quantities of "bird-resistant" sorghums.

Waxy sorghum varieties and hybrids have improved feed efficiencies when fed to ruminants and swine (Rooney and Pflugfelder 1986). The improved feed efficiencies of waxy sorghums have not been observed for poultry rations, probably because of the gizzards present in fowl. The processing properties and appearance of some yellow endosperm types of sorghum have been improved, thus gaining acceptability with farmer-feeders. No evidence exists to show that differences in sorghum pericarp color affects feeding value. However, the appearance of white and true yellow endosperm sorghums in feeds is superior to the reddish sorghum rations. For that reason, farmers in some areas of the United States sorghum belt are definitely sowing more true yellow endosperm and white sorghums. That trend will expand as seed companies respond with better sorghum hybrids.

Sorghum Phenols and Tannins

Because confusion concerning sorghum phenols and tannins exists (Hahn et al. 1984, Rooney and Miller 1982), a brief summary of our current understanding of sorghum tannins is included here.

All sorghums contain phenols which can affect the color, appearance, and nutritional quality of grain and products. The phenolic compounds can be divided into three basic groups: phenolic acids, flavonoids, and tannins. All sorghums contain phenolic acids and most contain flavonoids. However, only the brown, high-tannin, bird-resistant sorghums contain condensed tannins. Hydrolyzable tannins (tannic acids) have not been found in any sorghums. Sorghums without pigmented testae do not contain condensed tannins and have acceptable feeding value. They are often erroneously referred to as low-tannin sorghums. In fact, they do not contain any tannins. The low-tannin values reported in the literature are obtained when non-tannin phenols react with vanillin to produce color. Many of these values were reported in the older literature when it was unclear what tannins were.

The brown, bird-resistant, tannin-containing sorghums have unique kernel structures (Rooney and Miller 1982). Tannin-containing sorghums always have prominent pigmented testae located beneath the pericarp. The pigmented testa is purple or reddish brown and varies in thickness. It can often be detected by scratching the surface of the kernel with a knife or razor blade. During kernel development, the testa is formed from the inner integument. Remnant cells of the inner integument are found in all sorghums; thus, reference to sorghum without a testa really means that the sorghum has no testa. This tissue is sometimes referred to as an unpigmented testa.

All sorghum kernels with a pigmented testa are classified as brown sorghums, according to guidelines of the USDA Federal Grain Inspection Service. Brown sorghum can be distinguished from other sorghums by the Clorox® bleach test, in which 15 g of the sorghum sample, 15 g potassium hydroxide, and 70 mL of 5% NaOCl are (a) mixed in a flask, (b) heated in a water bath for 10 min with occasional shaking, (c) rinsed thoroughly, and (d) blotted dry. The bleach test is relatively simple and is the best method for determining the percentage of brown kernels in a market sample of sorghum. Kernels with pigmented testae turn black; those without testae remain light in color.

The bleach test can best be accomplished by including checks of known high-tannin brown sorghums, and non-tannin sorghums. The operator will thus know that the test is working. Although several factors affect the bleach test, the use of check samples insures desirable results. It should be understood that dark-colored spots occasionally appear on non-tannin sorghums when the bleach test is conducted. The NaOCl solution loses its oxidizing power upon prolonged storage.

Tannin Analyses

Several methods are used for quantitive tannin analyses (Earp et al. 1981). Leucoanthocyanidins (catechins) and proanthocyanidins (tannins) react with vanillin in the presence of HCl to give a bright red color. This is the basis for the colorimetric vanillin-HCl procedure and all of its modifications. Vanillin reacts primarily with flavonols (leucoanthocyanidins), but other flavonoid compounds give significant color development (i.e., dehydrochalcones). The Prussian blue, Folin-Denis, and Folin-Ciocalteau procedures measure phenolic acids, flavonoids, and tannins. These assays are based on the reducing power of phenolic hydroxyl groups. The tests even measure the content of the amino acid tyrosine in the proteins of sorghum. Thus, protein shows up as tannins when general phenol tests are used for analyses.

The glumes of sorghum contain relatively high levels of non-tannin phenols (Doherty et al. 1987) that are measured as "tannins" by general phenol assays.

Thus it is possible for a non-tannin sorghum which contains a large amount of glumes to indicate a higher "tannin" content than a brown bird-resistant sorghum without glumes.

None of these methods gives accurate measures of the actual quantity of condensed tannin in sorghum. The standards commonly employed do not provide the same absorption spectra as pure sorghum tannin. When marketing sorghums, the best practical method is to use the bleach test to determine whether brown sorghums are present. Then, the vanillin-HCl method can be used to determine the relative levels of condensed tannins in samples containing brown sorghum. Tannin analyses are not needed if brown sorghum is not present.

Sorghum kernels without a pigmented testa do not have condensed tannins, but values for catechin equivalents are reported in the literature. These values originate from non-tannin flavonoid components of the grain that react with vanillin under acidic conditions. Most of this background absorbance can be removed by using appropriate blanks during analyses.

The literature is confusing because all sorghums contain phenolic acids, flavonoids, and their esters, some of which can give a positive response to tannin analyses. We do not have absolute values for tannins (proanthocyanidins) in sorghum, and the values in the literature should be used only as relative estimates for comparing tannin levels among brown sorghum varieties. Sorghums without pigmented testa do not have condensed tannins, and their nutritional value is 95% the value of maize.

Acknowledgments

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Discussion

J.E. Cecil: What happens to tannin when it is "polymerized" by soaking the grain in acid/water/alkali?

L.W. Rooney: The condensed tannins interact with the constituents of the kernel, the reaction apparently initiated by the water. In other cases, apparently the binding sites on the condensed tannins are altered or perhaps occupied by the ammonia. The end result is that the tannins cannot be extracted and the levels are therefore reduced in the treated grain. Thus the tannins are effectively eliminated.

J.E. Cecil: Can you give approximate prices of sorghum and maize in the USA?

L.W. Rooney: Sorghum costs about \$75–80 t^{-1}, which is less than the cost of corn. Sorghum is used in all livestock rations depending on its cost relative to other grains. When sorghum is 10% lower in price than maize, sorghum is utilized.

A.C. Moshe: Cooking tends to reduce digestibility of sorghum as shown by in vitro rat studies and in vitro pepsin digestibility studies. Was the same observed in swine and cattle?

L.W. Rooney: Sorghum and corn were cooked with and without alkali and fed to pigs. The results indicated that the protein digestibilities of sorghum cooked with and without alkali were 5% lower than those of maize products prepared in the same manner.

We concluded that cooking did not lower the digestibility of sorghum significantly, and that sorghum's nutritional value for tortillas is only slightly lower than that for maize.

Sorghum and Millets as Forage Crops in the Semi-Arid Tropics

J.D. Reed[1]

Abstract

Sorghum (Sorghum bicolor *[L.] Moench) and pearl millet* (Pennisetum glaucum *[L.] R.Br.) are grown primarily as forage crops in the USA and Australia, but in smallholder farming systems in the semi-arid tropics they are multipurpose crops, providing food, feed, construction material, and fuel. Forage millet and sorghum are good silage crops in highly mechanized agricultural systems. Silage-making is difficult for the smallholder, and cut-and-carry systems are more appropriate. These systems require cultivars that ratoon. The effects of breeding for increased yields on nutritive values of forage and crop residues merit consideration. The proportion of cell wall in relation to other tissues in forage sorghum and millet is high. Digestibility of the cell wall carbohydrates is limited by lignin and related phenolic compounds. Brown midrib mutants of sorghum have altered lignic composition and greater digestibility of the cell wall. Red phenolic pigments in sorghum are also associated with lower digestibility. The cyanogenic glycoside dhurrin (in sorghum) and alkaloids (in millet) also lower nutritive value.*

Introduction

The International Livestock Centre for Africa (ILCA) has chosen mixed crop livestock smallholder farmers as the main target group for its research priorities because smallholder systems allow concentration on the key area of crop/livestock interactions, of vital importance to increase African food production (ILCA 1987). Animal nutrition and the utilization of feeds for improving ruminant production is a central theme in these research priorities. This paper discusses the potential of sorghum and millet as forage crops in the semi-arid tropics within the context of smallholder crop/livestock farming systems.

Potential as Forage Crop

At present the greatest use of sorghum and millet forage is in developed countries which have growing seasons characterized by high temperatures and low rainfall. They are used primarily as silage crops but are also occasionally used for green chop feed and hay.

The most important aspect from the standpoint of the transfer of these production systems to smallholder farming systems is that they require a high degree of mechanization. Successful silage from sorghum and millets requires tractor-drawn, power-take-off-driven choppers or electrical- or diesel-powered stationary choppers. Hand-powered choppers are much less effective and require a large labor input. In Africa, smallholder farmers do not have access to or capital for purchasing these machines. It is therefore unlikely that they would use millet and sorghum as silage crops.

Cut-and-carry forage production may be more suited to smallholder production systems. This method of harvesting is frequently used in zones with perennial napier grass (*Pennisetum purpureum*). The regrowth is cut at 4-6 week intervals and fed directly to cattle. The development of sorghum and millet varieties with good ratooning ability would be useful for extending cut-and-carry forage production to semi-arid zones. The hybrids of sorghum *(Sorghum sudense × S. bicolor)* and millet *(Pennisetum purpureum × P. glaucum)* may also be useful in extending cut-and-carry forage production in semi-arid zones (Mul-

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doon and Pearson 1979). The hybrids are reported to have higher nutritive value than the forage species (Hanna and Monson 1980).

Potential as Multipurpose Crops

Cultivars that can be used for forage and grain production allow farmers greater flexibility in choosing when to harvest in relation to grain and fodder value. Tall sorghum varieties are grown in the eastern Ethiopian highlands. Lower leaves are stripped from the plant during the growing season to provide cattle forage. After grain is harvested the stalks are used for fuel. In order to gain acceptance by these farmers, therefore, improved varieties with higher grain yield must also supply adequate yields of feed and fuel.

The importance of the multipurpose use of sorghum and millet is demonstrated in the smallholder production systems in the semi-arid trcpics of India. As much as 50% of farmers' income from the sorghum crop comes from the sale of the crop residue at urban fodder markets (Walker 1987). The stover is purchased by peri-urban dairies which supply the high urban demand for milk. The dairy operators perceive differences in the quality of sorghum stover and prices are lower for hybrid sorghum stover (Pathasarathy Rao 1985).

Factors Affecting Nutritive Value

The cellular and molecular components in forages can be divided into three classes of bioavailability (Table 1) (van Soest 1982). Class 1 consists of components in the cell contents (cytoplasm) that are completely available to digestion by microbial and mammalian enzymes. Class 2 consists of the cell wall carbohydrates that are only partially available for digestion by microbial enzymes and not available for digestion by mammalian enzymes. Class 3 consists of components in the cell wall that are not available for digestion by microbial enzymes in anaerobic systems and therefore limit the digestibility of other forage components. Lignin and related phenolic compounds are the most important components in Class 3.

The detergent system of forage analysis separates the components of forage based on this classification of bioavailability by separating cell contents from cell wall components through extraction with neutral detergent (Table 2) (van Soest 1967). Components in Class 1 are soluble in neutral detergent. Components in Class 2 and Class 3 are insoluble in neutral detergent and are collectively recovered in neutral-detergent fiber (NDF). Components in Class 2 and Class 3 are separated by sequential extraction in acid detergent followed by the determination of lignin. Although there are several forage components that do not entirely fit within this classification scheme (Reed 1986), it is nevertheless an extremely useful tool for understanding factors that limit the nutritive value of forages.

Sorghum and millet, like other species of grasses with the C4 photosynthetic pathway, have rapid rates of cell elongation and accumulation of cell wall carbohydrates during vegetative growth (Volenec et al. 1986). The digestibility of the cell wall carbohydrates as determined by their association with lignin and

Table 1. Classification of the bioavailability of forage components.

Component	True digestibility	Limiting factor
Class 1 (Completely available)		
Soluble carbohydrates	100	Intake
Starch	90+	Passage
Protein	90+	Fermentation
Class 2 (Partly available)		
Cellulose	Variable	Lignin, silica, and cutin
Hemicellulose	Variable	
Class 3 (Unavailable)		
Lignin	Indigestible	Limits cell wall digestion
Silica	Indigestible	
Tannins	Indigestible	Inhibits protein digestion

Source: van Soest 1982.

Table 2. Division of forage components by the detergent system of forage analysis.

Fraction	Components	Availability
Cell contents (soluble in neutral detergent)	Lipids, sugars, pectin, nonprotein N, soluble protein	Almost completely available and not lignified
Cell Wall (neutral detergent fiber)		
1. Soluble in acid detergent	Hemicellulose, fiber-based protein	Partially digested depending on lignification
2. Acid detergent fiber	Cellulose, lignin, lignified N	Partially digested depending on lignification

Source: van Soest 1967.

related phenolic compounds has a large influence on nutritive value.

In sorghum, high levels of phenolic pigmentation are associated with higher levels of lignin and lower digestibility of cell wall carbohydrates as measured by in vitro digestibility of NDF (Fig. 1 and Fig. 2) (Reed et al. 1987, Reed et al. 1988). Both variety and site have significant effects on lignin, pigmentation, and digestibility of NDF. The effects of variety and site on digestibility, lignin, and pigmentation was greatest in the leaf sheath fraction from highly pigmented bird-resistant varieties (Table 3).

Pigmentation may also affect intake of sorghum crop residue (Table 4) (Reed et al. 1988). Although MW 5020 had the highest proportion of leaf, this

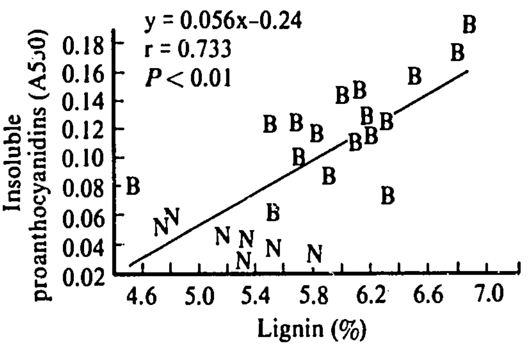

Figure 1. Relationship between lignin and insoluble proanthocyanidins in leaves from the crop residue of bird-resistant (B) and nonbird-resistant (N) sorghum.

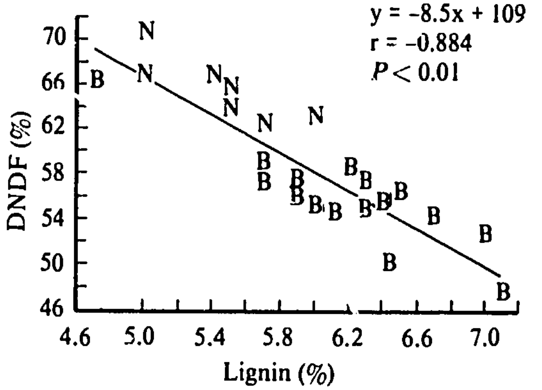

Figure 2. Relationship between digestibility of neutral-detergent fiber (DNDF) and lignin, and betweeen DNDF and insoluble proanthocyanidins in leaves from the crop residue of bird-resistant (B) and nonbird-resistant (N) varieties of sorghum.

Table 3. Effect of variety and site on content of lignin, soluble red pigments (550 sol.), insoluble proanthocyanidins (550 insol.) and neutral detergent fiber (NDF) and digestibility of NDF (DNDF) in sorghum leaf sheaths.

	Debre Zeit		Melkasa			Significant	
	BR	NBR	BR	NBR	SD	Site	Variety
Lignin (% OM)	6.3	5.7	6.1	5.8	0.6	NS	*
A 550 sol.	0.14	0.03	0.57	0.05	0.10	**	***
A 550 insol.	0.04	0.02	0.19	0.03	0.04	***	***
NDF (% OM)	79.1	79.4	77.0	78.3	1.9	**	***
DNDF (%)	51.2	56.6	42.8	55.3	2.7	*	***

BR = Bird-resistant.
NBR = Nonbird-resistant.
OM = Organic matter.
NS = Not significant ($P < 0.05$).

* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

Table 4. The effect of sorghum variety on the intake of crop residue by oxen.

Variety	Leaves in feed offered (%)	Leaves in feed refused (%)	Mean intake (kg day^{-1}) (n=5)
Buraihi	23.2	0	4.43^{a}
5DX-160	35.3	0	5.18^{b}
2k—x17	37.9	0	4.90^{b}
MW 5020	43.7	24.8	4.11^{a}
Melkamash	39.3	0	4.96^{b}

Means with different superscripts are signifcantly different. ($P < 0.05$).

highly pigmented dwarf variety had very low intake compared to other varieties. MW 5020 was the only variety with a significant amount of leaf fraction in the feed refusals.

Low molecular weight phenolic acids are also important in limiting the digestibility of cell wall carbohydrates (Akin 1982, Akin and Rigsby 1985). The major phenolic acids associated with the cell walls of grasses are ferulic and p-coumaric (Hartley and Jones 1977). These compounds are esterified to xylans (Mueller-Harvey et al. 1986). The brown midrib mutants of maize and sorghum have higher digestibility of cell wall carbohydrates than their normal counterparts and commercial varieties and a lower concentration of lignin and p-coumaric acid in the cell wall (Porter et al. 1978, Barnes et al. 1971, Muller et al. 1971, Akin et al. 1986, Cherney et al. 1986). There has been some interest in incorporating the brown midrib mutation into commercial varieties.

Less research has been conducted on the nutritive value of millet forage and crop residue than that of sorghum. The effect of variety on digestibility of NDF in leaf blades, leaf sheath, and stems was significant (Table 5) (Reed et al. 1988). However, the range

Table 5. The effect of variety on content of neutral-detergent fiber (NDF), digestibility of NDF (DNDF), and content of lignin in leaf blades, leaf sheaths, and stems from the crop residue of 12 millet varieties.

	Mean	Range	Significance of variety
Leaf blade			
NDF (% OM)	59.9	57.7 - 63.0	**
DNDF (%)	60.1	55.7 - 62.2	***
Lignin	3.9	3.5 - 4.5	**
Leaf sheath			
NDF (% OM)	69.2	65.5 - 70.8	**
DNDF (%)	42.4	38.1 - 44.9	***
Lignin	5.1	4.8 - 5.9	NS
Stem			
NDF (% OM)	76.2	72.5 - 79.6	**
DNDF (%)	30.7	27.6 - 35.2	*
Lignin (% OM)	8.7	7.6 - 9.7	***

OM = Organic matter.

* $P < 0.05$
** $P < 0.01$
*** $P < 0.001$

in digestibility of NDF among varieties of millet was narrower than for sorghum. The mean digestibility of NDF in leaf sheath and stem was much lower in millet than in sorghum. These millets were from an advanced agronomic trail at the ICRISAT Sahelian Center in Niger and represented both improved and local varieties.

The nutritive value of the leaf sheath and stem is well below the maintenance requirements for cattle. It is normal practice in Niger for farmers to leave the millet crop residue in the field to be grazed by cattle, although feed supply is limited during the dry season. However, the low nutritive value of leaf sheath and stem indicate that it may not be worth the effort to harvest and store the crop residue.

Conclusion

The use of crop residues as feeds as well as other uses such as fuel and construction cannot be ignored in crop improvement programs for the smallholder farmer. Practices such as leaf stripping and the thinning of plants at high population densities are strategies that farmers already use to insure a more reliable supply of scarce feed resources. The economic value of the sale of crop residues for use as forage by livestock specialists may also be important. The effects of breeding for increased yield and disease resistance on the nutritive value of forage and crop residues need to be determined. More research is required on the interaction between agronomic practices and cultivars of sorghum and millet for use as forage or multipurpose crops for the semi-arid tropics.

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Discussions

R. Schaffert: Did you observe any plant phenotypic differences between the 12 sorghum cultivars when you evaluated the digestibility of the NDF portion of the crop residue? Have you evaluated the nutritional differences between tan and red plants?

J. Reed: Pigmentation was the most important parameter in lowering the digestibility of NDF in leaf blades and leaf sheaths. Our bird-resistant varieties had the largest amount and showed greater variation in pigmentation than the non-bird-resistant varieties. Most of our non-bird-resistant varieties were tan plants and the bird-resistant varieties were red and purple.

R. Jambunathan: What is the in vitro method used and what is the correlation coefficient between in vitro and in vivo methods?

J. Reed: We use a 48-hour fermentation by rumen micro-organisms under strict anaerobic conditions. After the fermentation we isolate the remaining NDF and express our results as digestibility of NDF. Correlation coefficients between in vitro and in vivo methods are about 0.85–0.9.

A.B. Obilana: In our study in Nigeria at Shika Napri using improved varieties of sorghum and millets compared with local varieties and maize, we found an average of 1:4 for grain:crop residue. What is your experience in Ethiopia and India? What do you think should be our main thrust for southern Africa—forage or crop residue?

J. Reed: The ratio is highly variable, but about 1:4 in traditional varieties. Yield of plant fraction, such as leaf yield and stem yield per hectare, are also important factors to the farmer. Crop residue utilization should be emphasized in the short term. The introduction of forage types should occur at a later stage for smallholders.

S.C. Gupta: The study at ISC on 12 varieties is limited to only West African millet where stems are thick and tall. This could be the reason why millet stems are less digestible than sorghum stems. This may not be true with high-tillering, thin stem millets such as those of Indian varieties.

J. Reed: I am not satisfied that the ISC results represent the full range of millets. We are extending this research to include a greater diversity of material from both India and West Africa.

Digestibility of Sorghum and Millets in Foods and Feeds: The Effects of Processing

J.D. Axtell[1]

Abstract

Several years ago, Graham et al. (1986) reported that the protein digestibility of cooked sorghum is markedly lower than that of other cereals when fed to young children recovering from protein malnutrition. Nitrogen absorption was as low as 46% in these trials, conducted at the Nutrition Institute in Lima, Peru. Several follow-up studies have now been completed, using traditional village-processing techniques prior to the feeding experiments. The data clearly show that fermented breads, such as kisra *from Sudan, markedly enhance the protein digestibility of sorghum grain. Other traditional village-processing treatments have now been shown to also significantly improve the nutritional value of sorghum. The mechanism responsible for the observed differences between sorghum and other cereals is probably related to the cross-linked kafirin fraction in sorghum. Data are presented to support this hypothesis. Genetic variation for this trait exists among cultivars in the world sorghum collection, suggesting that progress can be achieved through breeding as well as through processing technologies.*

Introduction

The observed differences in protein digestibility between sorghum, maize, and millet may be related to differences in the Landry-Moureaux protein fractionation patterns between these cereals (Landry and Moureaux 1970, Axtell et al. 1982). Table 1 illustrates the protein fractionation pattern of some typical cultivars of each of these three cereal species. The percentage of total protein in Fraction III is very low for the millets, intermediate for the maize varieties, and higher for the sorghum varieties.

This cross-link prolamine fraction seems to be correlated with in vitro protein digestibility (Ejeta et al. 1987). The data in Table 2 dealing with in vitro protein digestibility of millets, maize, and sorghum substantiates the argument that the cross-linked kafirin fraction is negatively correlated with protein digestibility following cooking. A working hypothesis is that a cross-linking between sulfhydral groups in Fraction III proteins form complexes during cooking that reduce protein digestibility.

Table 1. Nitrogen distribution in whole seed of pearl millet, sorghum, and maize.

			Fraction of total protein (%)				
Cereal	Variety	Protein in seed (%)	I	II	III	IV	V
Millet	52731	14	22	41	7	9	21
Millet	Kordofani	12	27	40	5	5	11
Millet	Zongokolo	12	29	38	0	9	16
Sorghum	Redlan	13	10	16	31	4	29
Sorghum	P721-N	11	17	15	21	7	31
Sorghum	P721-0	12	24	6	11	7	45
Maize	Yellow Dent	–	20	34	10	10	16
Maize	SX 52	11	17	39	10	10	20
Maize	Opaque-2	10	39	12	6	12	32

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Axtell, J.D. 1992. Digestibility of sorghum and millets in the foods and feeds: the effects of processing. pages 179–181 *in* Utilization of sorghum and millets (Gomez, M.I., House, L.R., Rooney, L.W., and Dendy, D.A.V., eds.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

A preliminary search of the world sorghum germplasm for variability in the amount of prolamine protein in Fraction III versus Fraction II has been completed. One world collection entry, IS-2319, has been found to have a lower proportion of Fraction III storage proteins, but has maintained the relative proportion of Fraction II prolamines (Table 3). Studies are in progress to examine the in vitro protein digestibility of IS-2319 grain. It is interesting to note that this line was first identified by D.L. Oswalt as a cultivar with exceptionally good feeding value in rat trials conducted over several years at Purdue University. It was always used in these studies as the check variety in terms of biological value in rat-feeding experiments. Further work is needed on the heritability of this trait and the digestibility of cooked grain IS-2319 in future in vivo feeding experiments.

Table 2. Effect of cooking on pepsin digestibility of millet, maize, and sorghum.

Cereal	Variety	Protein digestibility (%) Uncooked	Cooked
Millet	Kordofani	91 ± 1.8	87 ± 2.3
Millet	Zongokolo	89 ± 3.9	85 ± 2.5
Maize	Yellow Dent	82	82
Sorghum	P721-N	82 ± 0.2	56 ± 0.2
Sorghum	P721-O	88 ± 0.9	73 ± 0.9

Table 3. Nitrogen distribution in whole seed of a highly digestible cultivar from the world collection.

Entry	Protein in seed (%)	Landry-Moureaux fraction Protein Total protein (%) I	II	III	IV	V
P721-N	13.13	15	17	22	5	33
P721-O	14.36	23	8	9	4	44
IS-2319-12	12.34	18	15	9	5	41
IS-2319-2	12.81	18	16	9	5	41
IS-2319-3	13.36	19	14	12	6	40
IS-2319-4	12.42	19	15	8	5	44
IS-2319-5	12.07	21	13	8	4	41
IS-2319 (average)[1]	12.60	19	15	9	5	41

1. Data on IS-2319 represents 5 individual heads numbered I through V.

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Discussion

S.Z. Mukuru: Have you determined the in vitro protein digestibility of the line from Sudan that has low fraction III and low fraction II? If so, what happens to its in vitro protein digestibility after cooking?

J. Axtell: The line from Sudan with normal fraction II content but low fraction III content does not decrease in in-vitro protein digestibility after cooking. In vivo trials have not been completed.

A.B. Obilana: When I was at Purdue in 1986 I got some seeds of the 'red plant' sorghum from Gebisa. What is this in relation to the high-lysine situation?

J. Axtell: The red plant mutant is associated with high protein content but has normal lysine content. A complete description of this mutant has been published in the **Journal of Heredity** and reprints are available from Gebisa.

A. Carney: What are the implications of the sorghum digestibility in cooking of composite flours and in semi-wet milling?

J. Axtell: The low fraction III line from Sudan has only recently been identified. We do not have any information on food quality characterization yet, but Dr Kirleis will be studying this in his laboratory at Purdue.

O. Olatunji: What is responsible for the reduced digestibility of cooked sorghum compared to the other cereals?

J. Axtell: This is a good question and I wish we had a complete answer for you. My working hypothesis is that fraction III storage proteins which are high in sulphuric amino acids are involved in cross-linking during cooking, which reduces digestibility unless it is properly processed. I emphasize that traditional village processing procedures make sorghum as digestible as other cereals.

Small Grains in Monogastric and Ruminant Feed Formulations: Prospects and Problems

C.D. Amira[1]

Abstract

Maize grain and its milling byproducts, maize bran and hominy chop, are the main sources of dietary energy for ruminant and monogastric feeds in Zimbabwe. In view of the importance of maize as a major source of food for human consumption, and because only the higher rainfall areas of Zimbabwe are suitable for producing maize, it is clearly desirable to look at alternative sources of energy for livestock feed. Sorghum and millets, better adapted to the lower rainfall areas, offer an alternative to maize for the feeding of livestock. However, very little use of these grains is found in commercial animal feed production due to such factors as: (a) pricing; (b) need for supplementation of poor protein content; and (c) cost of processing. This paper looks at the animal feed industry in Zimbabwe, reviews literature on the use of small grains within the livestock industry, and gives recommendations on the use of products from these grains for the commercial feeding of livestock.

Introduction

Maize (*Zea mays* [L.]) grain and its milling by-products, maize bran and hominy chop, are the main sources of dietary energy for ruminants and monogastrics in Zimbabwe. In view of the importance of maize as a major source of food for human consumption, and because only the higher rainfall areas of Zimbabwe are suitable for producing maize, it is clearly desirable to look at alternative sources of energy for livestock feed. Sorghum and millets, because they are better adapted to the lower rainfall areas, offer alternatives to maize for feeding livestock. However, very little use of these grains is found in commercial animal feed production due to factors such as pricing, the need for supplementation of poor protein content, and the cost of processing.

This paper examines the animal feed industry, reviews literature on the use of small grains within the livestock industry, and gives recommendations on the use of these products for the commercial feeding of livestock.

The Animal Feed Industry

Zimbabwe's highly developed stockfeed industry plays a vital role in the improvement of the beef, dairy, poultry, and swine industries, thus contributing to the country's program of self-sufficiency in human food of animal origin.

During 1987 it was estimated that local sales in the manufacturing industry amounted to approximately 114 million Zimbabwean dollars (Z$) and 425 000 t in volume.

These figures do not include animal feeds manufactured on farms mixed with concentrates supplied by the animal feed manufacturers. Total feed used on farms, therefore, totaled about 635 000 t valued at approximately Z$ 153 million. An estimate of the total feed sales by the animal feed manufacturers classified by livestock group is shown in Table 1.

Table 2 shows the estimated raw materials used to produce the 425 000 t animal feed manufactured by the industry in 1987. These figures do not include approximately 200 000 t maize which was used on

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farms or mixed with concentrates produced by the animal feed manufacturers. The table indicates that the commercial animal feed industry offers maximum replacement for only 120 000 t maize grain.

Table 1. Total animal feed sales for 1987 by manufacturers.

Feed category	'000 t
Dairy	125
Beef	155
Pig	35
Poultry	95
Miscellaneous	15
Total	425

Table 2. Raw materials used in 1978 by the animal feed manufacturers.

Locally produced	Average in feed (%)	Tonnes
Maize grain	28.2	120,000
Maize by-products	19.8	84,000
Wheat by-products	12.2	52,000
Cottonseed meal	9.6	41,000
Soy bean meal	10.6	45,000
Sunflower seed meal	1.1	4,500
Groundnut meal	0.7	3,000
Molasses	5.3	22,500
Meat and bone meal	1.2	5,000
Blood meal	0.3	1,100
Limestone flour	1.5	6,500
Monocalcium phospate	0.4	1,700
Cottonseed hulls	5.3	22,500
Miscellaneous products	0.6	2,600
Total	96.8	411,400
Imported		
Urea	1.5	6,300
Fish meal	0.1	450
Salt	1.4	6,000
Feed additives	0.2	850
Total	3.2	13,600

Biological Evaluation of Small Grains with Farm Animals

Sorghum grain has been considered less valuable than maize because of its highly variable chemical composition and lower feeding value.

In Zimbabwe, sorghums are grouped into red and white categories. White sorghums are preferred for food. The red sorghums contain brown bird-resistant sorghums as well as red pericarp sorghums without testae. No attempts are made to separate red from brown sorghums. Varying levels of brown sorghums are present in the red sorghums grown in Zimbabwe. Perhaps the Grain Board could separate brown sorghums containing tannin from those with red pericarp. This would improve the overall value of sorghum for feed. Also, the price of sorghum (higher than maize) is unrealistic, relative to its feeding value.

Tannins contained in the brown sorghums reduce feed intake because of its grain astringency which decreases palatability. Another disadvantage of tannin is that it binds with digestive enzymes and proteins in the digestible tracts of animals. Tannins also tend to inhibit the activity of various enzyme systems including amylase and possibly lipases and proteases (Hulse et al. 1980). Red sorghums without pigmented testae do not have tannins.

The chemical composition and nutritive value of finger millet (*rapoko*) was reviewed by Hulse et al. (1980). Finger millet is an excellent source of calcium (it contains 35 times more than rice) and iron. It also possesses a reasonably high level of methionine, the major limiting amino acid of certain tropical regions.

Finger millet has protein levels of 7.89-8.76% in brown grains and 9.01-11.6% in white grains. An increase in protein and a decrease in calcium were reported with application of nitrogenous fertilizers.

The chemical composition of various cereal grains is shown in Table 3. Sorghum grain protein analyses are shown in Table 4.

Use of sorghum in poultry diets

Sorghum can be used as a substitute for maize for layer birds at 60% without egg yolk mottling (Fry et al. 1972). The relative deficiency of lysine and methionine seriously limits utilization. Hassan (1974) indicated that there was need for lysine and methionine supplementation for diets of sorghum with protein supplements of cottonseed meal, carcass meal, and sesame fed to laying hens in order to increase egg production.

Addition of methionine at 0.155 to brown sorghum/soybean meal diets for poultry can result in improved growth and overcoming feed intake depression in chicks (Elkin et al. 1978). This can be explained by the fact that methionine may detoxify the tannin, thereby reducing availability.

Table 3. Evaluation of small grains compared with maize.

Nutrient analysis (as is) (%)	Brown sorghum	White sorghum (darso)	Pearl millet	Finger millet (munga)	Maize
Crude protein	10.4	10.0	11.7	8.1	7.7
UDP dairy	5.2	5.0	3.2	2.4	3.5
TDN	72.7	79.0	78.0	77.4	85.0
ME (mcal kg^{-1}) (pig)	2.94	3.19	2.85	3.10	3.47
Crude fiber	2.1	2.0	2.9	2.1	2.3
ME (mj kg^{-1}) (dairy)	11.0	11.93	9.54	11.6	13.00
Fat	3.1	3.0	4.3	3.0	4.5
Ash	1.5	2.1	2.9	2.0	1.5
Calcium	0.08	0.04	0.02	0.35	0.00
Phosphorus	0.3	0.3	0.27	0.3	0.40
Available phosphorus	0.09	0.09	0.08	0.09	0.13
Sodium chloride	0.13	0.13	0.02	0.10	0.00
Magnesium	0.15	0.15	0.16	0.15	0.10
Sulphur	0.12	0.16	0.12	0.12	0.12
Lysine	0.18	0.22	0.23	0.18	0.24
Methionine	0.09	0.18	0.20	0.28	0.18
TSAA	0.18	0.27	0.54	0.30	0.37
Tryptophan	0.09	0.10	0.17	0.08	0.07

UDP = Undergradable protein
TDN = Total digestible nutrient
ME = Metabolizable energy
TSAA = Total source amino acid
Source: Atlas of nutritional data on U.S. and Canadian Feeds 1971.

Table 4. Crude protein content of sorghum varieties and hybrids grown in Zimbabwe.

Variety/hybrid	Crude protein (%) (N x 6.25)
Red Swazi A	10.3 - 13.9
DC 99	8.1 - 8.3
SV 1	11.2 - 11.6
SV 2	9.8 - 10.5

Source: Research and Specialist Services, unpublished.

Sorghum gives similar results to maize as feed for chicks, growing pullets, and laying hens (Smith 1967). More sorghum is consumed due to its lower metabilizable energy.

While maize can be totally replaced by low-tannin (0.11%) sorghum broiler feeds, high-tannin (0.92%) feeds can replace only half the total feeds (Zhenchuan et al. 1985). Toth and Halmagyi (1968) found that 40% maize in starting diets and 46% in finishing diets could be replaced by sorghum without impairing growth, efficiency, or skin color. Similar observations were reported by Turek, et al. (1966) where sorghum replaced 30% of maize in broiler rations.

Maize was replaced by sorghum by ratios ranging from 0% to 100% with no difference in food intake and efficiency conversion of feed (Ali et al. 1975).

Variation in performance with different replacement ratios could be attributed to variable tannin content in the sorghum varieties used. Tannins have been associated with poor performance of sorghum-fed broilers (Peterson 1969, Saxena and Pradhan 1978, Kirby et al. 1983). Feeding high-tannin bird-resistant sorghums has been associated with leg abnormalities characterized by bowing of legs and swelling of hock joints (Elkin et al. 1978).

Nutritive value of bird-resistant sorghums with high-tannin content can be improved by extraction of tannin before feeding (Armstrong et al. 1974), fat addition (Bornstein et al. 1968), use of reconstituted high-moisture grain, supplementing with methionine (0.15%) and choline (Connor et al. 1969, Armstrong et al. 1974).

Use of sorghum in pig diets

The relative feeding value of sorghum to pigs as a percentage of the value of maize is 90-97%, compared with wheat (100-105%), barley (90%), and oats (80-90%). The relative deficiency of lysine and methionine places serious limitations on the utilization of sorghum by pigs. The animal feed manufacturer must know the amino acid deficiencies of the sorghum in order to formulate diets and use synthetic amino acids to balance the rations. Cohen and Tanksley (1976) established that threonine is the second limiting amino acid (to lysine) in growing and finishing pigs fed on sorghum-based diets. Tryptophan was established as the third limiting amino acid in growing pigs.

Tannins have also been shown to have an adverse effect on the utilization of sorghum by pigs. Myer et al. (1986) evaluated the effectiveness of dietary methionine supplementation on improving the feeding value of soya-based diets containing bird-resistant (high-tannin) and non-bird-resistant (low-tannin) sorghum for growing and finishing swine. Addition of methionine was not effective in overcoming the detrimental effect of tannins on feeding value of bird-resistant sorghum for growing and finishing pigs.

Han and Ha (1977) found that partial or complete substitution of maize by sorghum in diets for growing and finishing pigs did not affect growth rate, but increased feed consumption and improved carcass quality. They concluded that although sorghum was inferior to maize in nutritive value, complete substitution of maize by sorghum was satisfactory if relative prices were comparable.

Quisenberry et al. (1970) reviewed the literature on the use of sorghum grain for feeding pigs and commented that it provided an excellent feed when adequately supplemented with lysine (0.13%) and methionine (0.13%).

Replacement of maize by 20% and 40% sorghum in diets for breeding sows had very little effect on litter size, litter weights, milk yield, or mortality (Jancic et al. 1975).

Use of sorghum grain in ruminant diets

Adequately processed sorghum grain may be 95% as efficient as maize. Hale (1984) recommended that sorghum be processed by grinding, pelleting, or rolling for diets of beef and dairy cattle or calves in order to be used efficiently. Efficiency of feed utilization declines linearly with increasing sorghum grain content of diets for fattening steers. Sorghum grain replaces maize with about 89% efficiency in fattening steer diets (O'Donovan 1974).

Use of pearl millet (*munga*) in poultry diets

Sanford (1972) reported that at equal protein levels, pearl millet (*Pennisetum glaucum* [L.] R. Br.) was equal to sorghum with respect to weight gain and feed efficiency in chicks.

Pearl millet used as a cereal source of energy for broilers resulted in slightly lower food intake, liveweight gain, and food conversion efficiency than maize, but was superior to sorghum. Final body weight and dressing percentage were significantly higher ($P<0.05$) (Mohamedan et al. 1986).

Use of pearl millet (*munga*) in pig diets

Calder (1955) reported that up to 75% of the grain component of pearl millet grown in Zimbabwe was satisfactory in pig feeds. Sharda et al. (1972) reported that pigs fed an all-maize diet gained weight faster and more efficiently than those on diets of 75% maize and 25% pearl millet. Pearl millet is a valuable ingredient in pig diets due to its quality of promoting firm white fat (Calder 1955). Replacement of maize by 50% pearl millet in baconer diets resulted in better baconer grades (Murray and Romyn 1973). This finding agreed with the findings of Calder (1955) in his work with baconers and porkers (Calder 1961). This led to the conclusion that pearl millet can replace a maximum of 75% maize (Calder 1961). Ergot content in pearl millet is high in the wet season and if fed to breeding sows during this period can cause agalactia.

Uses of finger millet (*Eleusine coracana* [L.] Gaertn.) in animal feeds

Calder (1961) reported that finger millet (*rapoko*) is more suitable for breeding stock than for young growing pigs and recommended that it be limited to 50% of grain in pig feeds. Finger millet has a lower nutritive value for fattening steers. Ward (1968) suggested that its substitution for maize not exceed 75%.

Potential for Small Grains in Animal Feeds in Zimbabwe

From the foregoing the following recommendations can be made.

1. Brown sorghum. In poultry the protein digestibility is very low and decreases in proportion to an increase in tannin content. Approximately 25% replacement of maize has no apparent effect, but 100% replacement reduces its value to about 73% that of maize in poultry diets. It is therefore suggested that the following upper limits should be observed.

- Broilers: maximum 12% content by mass.
- Layers: maximum 15% content by mass.
- Pigs: maximum 0% content by mass.
- Ruminants: maximum 30% content by mass.

2. White sorghum

- No limits on any class of livestock.

3. Pearl millets

- Broilers: maximum 50% content by mass.
- Layers: maximum 55% content by mass.
- Ruminants: no limit.
- Pigs: no limits, but should not be fed to growing sows because the ergot content may cause agalactia.

4. Rapoko

- No limits on any class of livestock.

Recommended maximum feeding levels are summarized in Table 5.

It is important to observe the decrease in protein quality of these small grains when they are stored longer than 12 months. Uma Reddy and Pushpamma (1986) reported significant decreases in protein quality and amino acids in sorghum stored for a period of 12 months. Insect infestation causes a further decrease in protein quality as well as decreases of lysine, methionine, and tryptophan content.

Table 5. Limitations on usage of fine-milled small grains for inclusion in feeds for various classes of animals.

Class of livestock		Small grains (maximum %) Brown sorghum	White sorghum	Pearl millet	Fryer millet
Poultry:	Broiler	12	No limit	50	No limit
	Layer	15	No limit	55	No limit
Pigs:	Growing	20	No limit	No limit	No limit
	Breeding	20	No limit	Nil	No limit
Ruminants		30	No limit	No limit	No limit

Processing of Small Grains

Most animal feed factories in Zimbabwe are geared to the bulk handling of maize. This involves bulk intake into silos for storage and subsequent conveyance to the hammermills for grinding. Once ground, it is also incorporated into the mixing process via a bulk handling system. Any change to the increased usage of small grains would therefore cause additional handling problems and increase manufacturing costs.

Small grains are generally more abrasive on grinding mill hammers and screens than maize and therefore cause greater wear and tear. Another negative factor is that small grains contain an average of 3% small stones and grit by mass. The increased handling costs necessary for processing small grains amounts to about Z$7.50 t^{-1}, as well as an extra Z$1.71 for the additional grinding cost per tonne for small grains.

Pricing of Small Grains

In an effort to increase revenue to communal farmers and to discourage the planting of hybrid maize seed in the low rainfall areas, the Zimbabwean Government, through the Agricultural Marketing Authority, introduced high producer prices for small grains.

Conclusion

Based on the foregoing, it is clear to see that potential exists for use of sorghum and millets in animal feeding, but due consideration must be given for the constraints of nutritional deficiencies, inhibitors, and cost.

In economically developed countries where small grains are used in animal feeds, deficiencies and inhibitors in nutrient quality can be counteracted by processing and supplementation. This is not feasible in developing countries, particularly those with foreign currency constraints.

Grinding therefore offers the only meaningful processing technique to be used in a country such as Zimbabwe. Research efforts by plant breeders should be directed towards improving storage quality, particularly by preventing protein degradation. Such efforts would increase nutrient quality and thereby enhance the value of small grains.

We cannot overemphasize the importance of sorghum and millet for use in animal feed in Zimbabwe due to their unique tolerance for adverse conditions. Given improved an pricing structure, the quantities of small grains in animal feed will increase.

The animal feed industry in Zimbabwe offers the potential use of 100 000–300 000 t y^{-1} for small grains. Maize will continue to be used with the on-farm concentrate mixers.

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Discussion

L.R. House: With sorghum there is interest in multiple crop use. Is there much feeding use for nongrain parts of the plant?

C.D. Amira: Yes, there are. Forage sorghums are now being grown on dairy farms to reduce dependence on maize, which is unsuitable as an energy source for high-lactating diary cows.

J.M. Mushonga: You mentioned that small grains stored for over 12 months decrease in protein content. Under what conditions are these stored?

C.D. Amira: They are stored in jute grain bags stacked out in the open. A tarpaulin is used to cover the stacks in case of rain.

N.F. Nicholson: What work has been done in Zimbabwe on increasing inclusion rates of high-tannin sorghum in poultry rations from present recommended levels by using supplemental methionine?

C.D. Amira: Because of the shortage of foreign exchange this work has not been carried out.

J.M. Chitsika: I understand from some communal farmers that stalks of some sorghum varieties have been attributed to deaths of cattle. What caused such deaths—boreworms or what?

C.D. Amira: I am not sure. I have not come across this phenomenon before.

A.R.H. Hawke: What was the source of pearl millet (*mhunga*) for the stockfeed industry until 1980 when this product was not controlled?

C.D. Amira: The stockfeed industry used to purchase *mhunga* exclusively from the communal areas in cash, which was most welcome. In addition, some *mhunga* used to be exported to South Africa for bird-seed, but this country now grows its own *mhunga* for this purpose. *Mhunga* was used 100% in pig fomulations in place of maize.

M.I. Gomez: Since the economics of the milling and hulling of sorghum for human food depends on economic disposal of bran, are you using the bran presently or planning to detoxify tannin by low cost treatments?

C.D. Amira: The maximum incorporation level is about 12%. There is no problem in dairy rations. In pig feeding, complete replacement of maize by sorghum is feasible.

L.R. House: Can you indicate the magnitude of feedlot activity in Zimbabwe?

C.D. Amira: Feedlot activity is quite extensive. Some 70 000-80 000 t of feedlot rations were used last year. The Cold Storage Commission runs large-scale feedlots for both commercial and communal farms. Commercial farms utilize maize in the form of snapped corn, mixed with a concentrated formulation in the higher rainfall areas. Most of Zimbabwe's beef exports to Europe come from these feedlots.

Working Group Discussions

The Methodology

A novel methodology consisting of four steps was developed at the workshop to obtain focused results from the working group discussions.

1. The participants were divided into multidisciplinary groups corresponding to the main topics of the workshop.

   - Group I: Primary Food Processing
   - Group II: Secondary Food Processing
   - Group III: Industrial Uses
   - Group IV: Feeds

2. A spreadsheet was designed for each working group, listing major factors affecting utilization and the major categories of utilization.

3. The input of group members was recorded in a few key words on cards. The cards were then pinned under the appropriate column of the spreadsheet. Thus both documentation and visualization of ideas were achieved.

4. Each product/process was then taken through a stepwise analysis, including a report on current status and a priority score.

The Format

The discussion format is a guide to structuring the working group discussions to obtain well-focused results consonant with the defined objectives. Utilization of sorghum and millets is examined in terms of known and potential technologies/products, their application, and their sustainability. It is hoped that this analysis, by providing a viable means of scoring/rating, will indicate the best courses of action for crop improvement programs.

The vertical columns define the scope of the discussion. Horizontal progression across the columns gives an overview of utilization, practice, potential, and viability. There are seven main headings.

1. Process. Provides the key to the discussions and lists the known and potential technology.

2. Product. Lists the corresponding products.

3. Level of application. Provides guidelines for analyzing the levels of application/practice of specific technologies/products. Relevant subheads are included (Research, Research and development, and Industrial applications).

4. Nutritional implications. This category is included in the spreadsheets dealing with foods and feeds.

5. Sustainability. Factors and causes contributing to positive (yes) or negative (no) sustainability. (This heading is not included in the spreadsheet on Industrial Uses).

6. Future work. Inputs needed to improve/establish sustainability and processes/products with potential.

7. Priority. A priority rating is assigned to each process (1=high, 5=low). (This heading is not included in the spreadsheet on Industrial Uses).

Discussion Spreadsheet - Primary Food Processing - Group I

Process	Product	Level of application: Research	Level of application: Research and development	Level of application: Industrial applications
1. Immature whole grain—roasting, boiling, popping, steaming, flaking	Roasted/boiled, puffed, steamed, flaked (Ethiopia, India, Uganda)	Processing research	Intermediate technology, for small-scale applications	Traditional
2. Whole grain composite, boiling/popping	Sorghum + legume (Nigeria)	-do-	–	Traditional
3. Whole (dry) grain roasting and grinding	Roasted grain (India, western Tanzania), Roasted dry flour (Zimbabwe)	-do-	–	Traditional
4. Whole grain treatment: acid/alkali/ash (AAA)	AAA treated grain (western Africa, Uganda)	–	–	Traditional/ rural (western Africa, Uganda)
Whole grain treatment: formaldehyde (pretreatment in brewing)	–	–	–	Formaldehyde in malting/ brewing)
Steeping	–	Acidulants and alkaline agents	–	–
5. Dehulling whole grain traditionally	Pearled grain + bran, kibbled grain (like mealie rice), boiled products	–	Small-scale	Traditional
6. Dehulling + pounding (grinding) traditionally	Meal (porridge) + bran	Low level	–	Traditional
7. Dehulling (mechanically)	Pearled grain + bran (rice analog)	Optimizing technology Varietal screening	–	Semi-industrial (Africa, Asia)
8. Dehulling, dry milling (hammer, roller) Other milling systems (e.g., UMS Decomatic)	Meal, offals (bran, etc.), flour and milled fraction, flour (refined)	-do-	Optimizing a milling system for small grains	Semi-industrial (SADCC region) Industrial (Nigeria)

Nutritional implications	Sustainability	Future work	Priority (1 = high, 5 = low)
High lysine varieties consumed as immature/ milk dough grain in Ethiopia	Western Africa, Ethiopia	Breeding and processing research—explore use in special foods (e.g., weaning food)	5–SADCC region (especially Zimbabwe) 3–Western Africa, Ethiopia, India
Complementary protein and amino acid balance	Botswana, Lesotho, Nigeria, Tanzania, Zimbabwe	Dissemination of nutritional advantages, commercial applications (e.g., *soyogi*)	1
Improved digestibility (?)	Snack food, school feeding	Explore industrial scale-up	5–SADCC region and global until more research is available
Reduction of phenols and tannins, improved nutritional quality	Yes	Scale-up of industrial application permitting use of high-tannin varieties for food	1
-do-	Yes	-do-	1
Reduction of tannins (?)	Yes	Research on nutritional and processing quality	More information needed
Increased palatability	Yes, but constrained by labor input	Grain characteristics for better dehulling (e.g., thick pericarp vitreous endosperm)	1
		Principles of traditional dehulling, conditioning, impact dehulling to loosen hulls to be researched as alternative to abrasive dehulling	
Increased palatability, keeping quality of millet	Yes	Research on breeding and on processing quality, especially for millets	3–sorghum 1–millets
Increased palatability, convenience	Potential subject to pricing policies (Sudan)	Grain characteristics (thin pericarp, vitreous endosperm). Value adding to bran—some bran fractions suitable for human food (good protein, fat, and energy content)	
		Rice analog, more research	
–	Dehulling, hammer milling (porridge meal)	Feasibility/viability of commercial mills in urban areas: breeding research, milling quality	2

Discussion Spreadsheet - Secondary Food Processing - Group II

Process	Product	Level of application: Research	Research and development	Industrial applications
1. Compositing/ blending	Bread, cookies, biscuits, pastas	Technology known (FAO/ECA, ODNRI, IRAT FIIRO, FRI, Sudan, ITA)	Yes	Yes, up to 10% in Zimbabwe (5% sorghum and 5% maize), possibly 25% potential for other SADCC countries
2. Nonwheat flour	Nonwheat bread, cookies, pastas	Little information	Research and development experimentation (Nigeria)	Potential for industrial application (Nigeria)
Dehulling/milling (composite or 100% small grain)	Porridge bases (thick/thin), dumplings	–	Yes (Botswana, Zimbabwe)	Traditional/industrial products
Agglomeration	Agglomerates (beverage base)	–	–	–
3. Fermentation	Clear beer	Technology known, subject to proprietary secrecy (e.g., malted beverages and brewing research in Nigeria)	Yes (Nigeria, Mexico)	Quality standards and processing technology for available analogs (e.g., milo) Semi-industrial quality criteria important (Nigeria)
	Opaque beer	Technology known	–	Africa
4. Acid fermentation	*Mahewu* (Zimbabwe) *Ting* (Botswana) *Uji* (Eastern Africa)	Technology known	–	Commercial (Botswana, Kenya, Lesotho), not as successful as formerly in Zimbabwe
5. Conversions from starch (chemical/ enzymatic)	Glucose, dextrins	Not available (Starch extraction from small grains more difficult than from maize or tuber crops)	Nigeria? Grain quality for starch extractability (India, Mexico, Sudan)	–
6. Formulations (cereal binders extenders)	Meat products (sausage, rusk)	Available (FIIRO, KIRDI, ODNRI)	Nigeria (FIIRO), Zimbabwe	Industrial potential exists
7. Starch hydrolysis (alcohol, acetic acid) sorbitol	Alcohol, acetic acid, citric acid,	As for (5)	As for (5)	As for (5)
8. Modification of starch	Modified starches	As for (5)	As for (5)	As for (5)

Nutritional implications	Sustainability		Future work	Priority (1 = high, 5 = low)
	Yes	No		
If dehulled protein supplementation with soya, etc.	Process sustainable	Product sustainability subject to ploicy/ pricing	More research needed on food quality, varieties, technology optimization for local seeds	1-SADCC
Partial replacement of wheat	Not applicable	–	Quality requirements of raw material and products Research on cultivars, especially for mixtures (ICRISAT, Tanzania) Research on milling and food quality (ICRISAT, ODNRI, Tanzania)	1–Botswana, Lesotho, Tanzania 2–Other SADCC countries 5-Zimbabwe
–	–	–	–	1-Botswana, Lesotho, Tanzania 2-Malawi 3-Other SADCC countries 4-Zambia, Zimbabwe
–	–	–	–	–
Important	Not applicable (product and process sustainable)	–	Acceptable varieties/ cultivars with required grain quality	1-SADCC generally 2-Tanzania 5-Zimbabwe
Not adequately researched	Process and product sustainable	Affected by pricing/ excise policy	Breeding and selection implications	1-SADCC 3-Zimbabwe
Important as food and beverages	Yes (commercial product declined in Zimbabwe)	–	Quality improvement	1-SADCC, as weaning food 2-SADCC, as beverages
–	Yes, potential only in small grain surplus countries (Zimbabwe, Malawi, Tanzania, Kenya)	No, in cereal-deficient countries (Botswana, Zambia, Mozambique, Angola, Lesotho)	–	5-SADCC generally
–	–	–	Selection of cultivar, use of reds, color not a problem	3-SADCC
As for (5)	Depends on viability of starch extraction and market demand	–	–	–
As for (5)	Depends on viability of starch extraction and market demand	–	–	5-SADCC generally

Discussion Spreadsheet–Industrial Uses–Group III

Process	Product	Level of application: Research	Research and development	Industrial applications
1. Sweet sorghum milling	Sugar juice, raw sugar, brown sugar, alcohol, bagasse (feed, fuei, cellulose)	Under study and development	Continuing	Started
2. Wet milling (grain)	Starch, sweeteners, syrup, sizing chemicals	Research complete	-	Yes, but not currently economical in USA
	Protein and oil fiber (dietary)	Depends on research on protein, oil, and fiber interactions	-	No, only if starch is economical
3. Dry milling (grain)	Industrial starch and flour, adhesives, core binding, ore refining	Research and technology available in USA and other countries	Yes	Yes, in USA, need to develop market, good potential
4. Dry milling (stover/straw)	Fuel pellets (from fines/waste), particle board	Research complete for other cereal straws (Denmark, USA) Research on going for sorghum and millets	Continuing	Yes, as for other cereal straws
5. Fermentation (sweet sorghum)	Alcohol (ethanol) stillage	Yes	Brazil	Yes, viable microdistilleries exist (Brazil)
	Biogas, biofertilizer	Yes	Brazil, India	Domestic village scale
6. Malting	Industrial enzyme from malt	Yes	Continuing	Potential in Nigeria

Nutritional implication	Sustainability	Future work	Priority (1 = high, 5 = low)
High-quality forage, improved carrying capacity, supplemental dry-season grazing	Process may not be sustainable for smallholder; competition with food crops	Ratooning varieties and interspecific hybrids, appropriate conservation needed	2–Global 2–SADCC
Low nutritive value requires improvement and variety development; supplementation (salt and bran)	Process can be used in existing systems	Supplement with legume forage, browse by-products, and greater quantities of harvestable leaves	1–Global 1–SADCC
Low nutritive value under low management to improve quantity of feed	Not sustainable in semi-arid tropics, only sustainable in high-rainfall areas	-	4–Global 5–SADCC
Effects of tannin on protein (positive effects in ruminants)	Economic value of bran important in milling industry and small-scale dehulling	Incorporate tannin brans in dairy cattle feed	1–Global 1–SADCC
Improved feed efficiency in beef feeds Improved value for cattle feed	Realistic pricing for grains (sorghum, millets, and byproducts)	Alternative uses of sorghum and millets as feed instead of food	4–Global 4–SADCC
Reduced tannin products (end product); improved feed value	Unknown	-	4–Global 4–SADCC
Improved rate of grain and feed efficiency: low fraction III protein; reduced cost of feed processing	Significant potential for improving animal production in SADCC region; important for poultry and swine	-	2–Global 2–SADCC
-	-	-	1-5–Global 1-5–SADCC

Discussion Spreadsheet – Feeds – Group IV

Process	Product	Level of application: Research	Level of application: Research and development
1. High moisture harvest	Green forage/hay	Varieties with better quality, competition with food crops, reduced polyphenols, brown midrib	Mechanized farming of sweet sorghum
2. Harvest	Crop residue	Dual-purpose varieties, new varieties with higher energy, economic returns to harvest, storage	Smallholders and commercial enterprises
3. Ensiling	Silage	–	Low application for dairy farms, no application for small-holders, highly mechanized systems
4. Dehulling	Bran	Treating high-tannin brans with alkali, level of tannin bran in diets, milling yield, and nutritive value of bran	–
5. Milling of grain	Dry milled, rolled, fine ground, pellet	Small-scale feed processing, long-term market for grain-fed cattle, technology treansfer (only hammermill viable)	–
6. Steam flaking, rolling, conditioning, reconstituting, pressure cooking, popping, micronizing	Flakes, popped products, etc.	–	Technology already available
7. Alkali treatment and local villabe processing	High-tannin grain (raw material)	Mineral soils for tannin detoxification *Magadi* salts (Tanzania) Soda ash plant being built (Botswana)	–
8. Improving grain quality for feed	Whole grain	Technology (research) Potential benefits of breeding Breed low-tannin bird-resistant varieties Improve carotenoid pigments in sorghum and millet grain by breeding	–

Nutritional implications	Sustainability	Future work	Priority (1 = high, 5 = low)
High-quality forage, improved carrying capacity, supplemental dry-season grazing	Process may not be sustainable for smallholder; competition with food crops	Ratooning varieties and interspecific hybrids, appropriate conservation needed	2–Global 2–SADCC
Low nutritive value requires improvement and variety development; supplementation (salt and bran)	Process can be used in existing system	Supplement with legume forage, browse byproducts, and greater quantitites of harvestable leaves	1–Global 1–SADCC
Low nutritive value under low management to improve quantity of feed	Not sustainable in semi-arid tropics, only sustainable in high-rainfall areas	–	4–Global 5–SADCC
Effects of tannin on protein (positive effects in ruminants)	Economic value of bran important in milling industry and small-scale dehulling	Incorporate tannin brans in daily cattle feed	1–Global 1–SADCC
Improved feed efficiency in beef feeds	–	Alternative uses of sorghum and millets as feed instead of food	4–Global 4–SADCC
Improved value for cattle feed	Realistic pricing for grains (sorghum, millets, and byproducts)		4–Global 4–SADCC
Reduced tannin products (end product); improved feed value	Unknown	–	2–Global 2–SADCC
Improved rate of grain and feed efficiency Low fraction III protein Reduced cost of feed processing	Significant potential for improvinganimal production in SADCC region Important for poultry and swine		1–5-Global 1–5–SADCC

Recommendations

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Primary Food Processing—Group I

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1. There is need to recognize and develop differential quality requirements of sorghum for traditional and commercial primary processing. For example, traditional dehulling preference is for thick pericarp and soft/intermediate endosperm grains, while commercial abrasive hulling/milling requires thin pericarp and vitreous grain. Processing research is needed to optimize traditional technologies with regard to the degree of conditioning for maximum milling yield, period of presoaking/pregermination, maximum removal of tannins, etc.

2. Several mechanical hulling/milling systems (such as modified wheat milling, abrasive dehulling, conditioning and impact, and semiwet milling) have been developed to the research and development and semi-industrial stage. Systematic comparative evaluation of hulling/milling performance of these systems (extraction rate, etc.), based on selected check varieties, is needed. Collaborative studies should be initiated.

3. Differential studies should be initiated on breeding/selection and processing systems for (a) porridge meal, and (b) baking flour and other milling fractions, such as semolina and grits.

4. Further research is needed on nutritional implications of traditional processing methods, notably acid/alkali treatments and possibilities of application on an industrial scale for treatment of sorghum grain as well as bran. This can be significant in extending the use of high-tannin brown sorghum grains for food.

5. Pearled sorghum rice analog has gone through research and development and has reached the test marketing stage in several countries (Sudan, Kenya, Botswana). Quality standards are still not optimized for color, grain size, texture, cooking quality, etc., in relation to appropriate varieties. Selection pressure is needed. Rice analog is an important commodity in SADCC countries that do not grow rice.

6. Malting is an important process, not only for production of opaque and clear beer but for food malts and weaning foods based on improved nutritional quality of malted grain. Grain selection in sorghum and millets for good malting quality is a high priority in the SADCC region, as well as in western and eastern Africa. Breeding and processing research need to be intensified for identifying grains with high diastatic units and high free amino nitrogen (for brewing malts), and those with moderate diastatic units and good flavor profile (for food malts).

7. Methodologies need to be standardized for quality evaluation, such as micromalting and diastatic activity determinations through interlaboratory trials on selected check varieties of sorghum and millets.

8. Research is needed to extend application of processing technologies, such as flaking and micronization, to human foods, and to optimize these processes for cost efficiency and nutritional and food quality.

9. Industrial processes such as extrusion cooking need to be explored as sources of pregelatinized sorghum flour and complementary cereal/legume precooked mixtures, such as *soyogi* in western Africa. Extrusion cooking capacity is now established in Botswana and Zimbabwe.

10. Chewing sorghums are widely consumed throughout the SADCC region, though their relative importance in diets is unknown. Industrial use of sweet sorghum for sugar and alcohol is not a high priority for the SADCC region, but where it is feasible (as in Brazil), selection for high sugar, low fiber, high extractability, and multiple ratooning is needed.

11. Introduction of high-lysine sorghums for milk, dough, and hard-stage consumption (as in Ethiopia) should be explored in the SADCC region. Acceptability should be tested, but not as a high priority.

12. Standardization of the physical, chemical, and functional quality testing methodologies (for grain hardness, tannin content, dough quality, and digestibility) through interlaboratory evaluations on a range of check varieties is needed.

13. There is a need to standardize terminologies regarding color descriptors and high and low tannin quantification.

Similarly, methods of measuring related qualitative descriptions should be standardized (for instance, hardness can be measured on an instrumental scale, a milling yield scale, or a particle size index scale). Implied in this is the need to identify a network of cooperating laboratories with resource capabilities in specific areas. A consensus was expressed that the SADCC/ICRISAT Sorghum and Millets Improvement Program should serve as a reference and coordinating center of such activity for the SADCC region.

Secondary Food Processing—Group II

Participants	Disciplines
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1. Composite flour technology for production of a range of products (bread, cookies, biscuits, and pastas), incorporating sorghum and millet flour, has been developed in many countries, including SADCC countries such as Zimbabwe. In wheat-importing countries, sorghum- and millet-based composite products are a high priority. Selection of varieties that show good milling/baking/extrusion characteristics and favorable pricing policies is desirable.

2. Countries with little or no wheat production should direct breeding and processing research to nonwheat products such as bread and biscuits. But the feasibility of nonwheat products is low in most SADCC countries unless wheat is not available at all (as in Nigeria). This recommendation is therefore given low priority.

3. Thin and thick cereal porridges are consumed throughout Africa. Considerable research relating grain quality to porridge quality is already available. More work is needed on a pilot scale to develop a ready-to-cook sorghum and millet porridge meal. Organoleptic problems with millet flour need to be studied to determine if they can be solved by varietal improvement or by processing.

4. Research and development and semi-industrial scale studies in Nigeria and Mexico have demonstrated the feasibility of 100% replacement of barley malt with sorghum malt in clear beer. There should be selection pressure for identification of varieties with high diastatic units for this purpose. This application is a high priority in countries dependent on imported barley malt and enzymes. It is a high priority for the SADCC region generally, and a medium to low priority for Zimbabwe, which has export capacity for barley malt.

5. Opaque beer, based on sorghum malt, is a traditional product in eastern and southern Africa. It is already commercialized in southern Africa. The product is a high-priority item as both food and beverage, but the technology still needs to be optimized, especially with regard to organoleptic and nutritional quality. Screening of both sorghum and millet varieties for good malting, gelatinization, and organoleptic quality is needed to extend the technology in SADCC countries. Grain and product quality research on such processes as acid fermentation in fermented porridges, which are widely consumed in the SADCC region, needs attention.

6. Low bulk, nutritionally adequate weaning food is a high priority for the whole SADCC region. Some research has been initiated in the region, as in Tanzania, but more research and development is needed to develop practical, low-cost weaning food formulae that include malt as the bulk-reducing agent. Both traditional use and commercial application need to be encouraged.

Industrial Uses—Group III

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1. **Sweet sorghum milling.** In many countries, there is a deficit of fuels and/or ethyl alcohol for industrial use. Technology has been developed for the extraction of the sugar from sweet sorghum biomass and for its transformation into alcohol. Depending on the demand and price of alcohol, this becomes a profitable enterprise with valuable by-products: grain, bagasse, and stillage. The grain has the same value as any other grain and may be utilized as a food or feed. The bagasse and stillage may be transformed into biogas and biofertilizer in energy-deficient regions. In this transformation of bagasse to biogas, animals may be used by feeding them the bagasse and using the manure to fuel the biodigester. The biofertilizer should be returned to the soil to maintain fertility. Cultivar improvement should focus on maximum alcohol production and maximum biological value of the bagasse for animal forage.

2. **Sorghum crop residue for biogas production.** In many regions, there is a shortage of energy for domestic uses and, as in Botswana, a shortage of energy to pump water for animal use. Sorghum residue can be used as the biomass source in a biodigester for production of biogas. The technology for this process already exists. Sorghum can be improved to produce more carbohydrates in the stalks (residue) to improve the yield of this process (sweet stalk type). This should not reduce the potential of grain production.

3. **Dry milling of grain.** Industrial starch is important and is already well commercialized to make such products as adhesives, as a core binder for well drilling, and in ore refining. As there is good potential for such uses, breeders should select grains with good dry-milling characteristics. In Zimbabwe, for example, a demand exists for waxy starch. Existing waxy endosperm hybrids and varieties should therefore be evaluated for industrial use and, if promising, bred for high yield.

4. **Wet milling.** Sorghums with the potential for wet milling to produce starch should be developed as part of the improvement program. Potential for use of waxy sorghum exists in certain areas. Sorghums for wet milling would have intermediate texture, yellow and perhaps waxy endosperm. This is not, however, a high priority.

5. **Dry milling of straw.** The products are fuel pellets, particle and building boards, and cellulose pulp for the paper industry. Research has been conducted on cereals other than sorghum. No pilot research and no industrial/commercial application exists for sorghum straw.

Sorghum is known to produce an extremely high amount of biomass, and it could be an important renewable energy resource. Fuel pellets can be produced from a meal obtained by dry milling. This meal consists of leaves, nodes, and pith. Another product obtained by the mechanical separation is a fraction from internodes. This fraction is high in cellulose and lignin, and chips could be used in particle and building boards or as raw material for the paper pulp cellulose industry. All writing and printing paper produced in Denmark contains an average of 30% bleached wheat and rye straw cellulose. Sorghum straw could be explored as an alternative.

Research and development is needed to obtain raw materials which, during dry milling, produce optimal fractions for those three products. This can be done in a collaborative study with Carlsberg Research Laboratory, where laboratory equipment is available.

Feeds--Group IV

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D.S. Murty	Breeder
J.F. Mushonga	Breeder

1. The development of dual-purpose sorghum varieties with improved forage quality and low-tannin grain is a high priority.

2. Alternative methods of bird control should be studied. Bird bait systems, where small plots of sorghum are sown near roosts to divert birds from large-scale production plots, are working in Zimbabwe. These are combined with spraying very effectively.

3. Breeding and research efforts to improve digestibility of sorghum grain should receive support. The genetic variation in sorghum germplasm should also be assessed for heritable variation in Landry Moreaux Fraction III storage protein. Improved varieties should be developed.

4. For use as high-moisture green forage, breeding efforts should be directed to interspecific hybrids, such as *Sorghum bicolor* × *S. Sudanense* and *Pennisetum glaucum* × *P. purpureum*, to forage cultivars that ratoon, and to improving nutritive quality in preference to yield. However, forage potential for smallholder cut-and-carry systems may not be sustainable where there is competition with food crops.

5. Crop residue utilization, on the other hand, is highly applicable to existing small-scale and communal farming systems. The importance of crop residue as feed, fuel, construction material, and industrial raw material should be given high priority in crop improvement programs.

6. Dual-purpose varieties with greater nutritive value of the crop residue for ruminants should be developed.

7. The economic and ecological impact of the increased use of crop residues for feeding livestock in competition with other uses should be determined.

8. A high priority should be given to exploring sources of alkali salt for treatment of high-tannin sorghum grain and bran to improve the feed efficiency of these materials for ruminant and monogastric feeds, and to determining the nutritive value and levels of grain and bran that can be incorporated into feeds. The economic implications of the use of bran from tannin-containing sorghum should be determined for the use of these sorghum varieties by the milling industry.

9. The introduction of the brown midrib mutation and other genetic manipulations that reduce the effects of lignin on forage digestibility should be studied.

10. Further research on the positive effects of tannins in sorghum bran on protein utilization by ruminants—especially by dairy cattle—should receive priority in order to extend the feed value of high-tannin brans.

11. The pricing policy for sorghum and millets, as we' as for other cereals, should be consistent with the biological and economic value of the crop.

12. Swine and poultry producers will be important consumers of sorghum and millets in the SADCC region, and crop improvement efforts should consider the use of grain in diets of simple stomach livestock in addition to cattle diets.

13. The use of sweet, juicy-stem varieties of sorghum in forage production systems should be considered. Consideration of sweet, juicy-stem types against nonsweet, dry-stem varieties may be useful.

14. Priority should be given to evaluating opportunity costs and returns to the use of sorghum and millet stover, grain, and bran for feeding draft animals before sowing to improve draft quality.

15. There is a need to explore opportunities and constraints relating to the use of feeds based on sorghum and millets, including forage and grain for fattening the cattle of small farmers for market sales, and to evaluate opportunities for stall or pen feeding strategies. This could form a potential basis for increasing small-farm incomes in the semi-arid zones.

16. Guidelines should be established for price and market adjustments necessary for stimulating greater use of sorghum and millet products in the formal and informal (farm-based) feed industry.

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Acronyms

BAMB	Botswana Agricultural Marketing Board
CE	catechin equivalent
CIDA	Canadian International Development Agency
CIRAD	Centre de Coopération international en recherche agronomique pour le développement (France)
CNPMS	Centro Nacional de Pesquisa de Milho e Sorgho (Brazil)
CRS	Catholic Relief Services
DLL	dehuller with linatex lining
DNL	dehuller with nonrubber lining
DRB	dehuller reduced barrel
DWL	dehuller without lining
EARCAL	Eastern Africa Regional Cereals and Legumes Program (Kenya)
EBC	European Brewing Convention
ECA	Economic Commission for Africa
EEC	European Economic Community
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuaria (Brazil)
ENDA	Environment Development Activities (Zimbabwe)
FAN	free alpha-amino nitrogen
FAO	Food and Agriculture Organization of the United Nations (Italy)
FEM	Foreign Exchange Market
FIIRO	Federal Institute of Industrial Research, Oshodi (Nigeria)
GASGA	Group for the Assistance with Systems Relating to Grains after Harvest
GMB	Grain Marketing Board (Zimbabwe)
HCN	hydrocyanic acid
HPLC	high performance liquid chromatography
HTST	high temperature short time
IAR	Institute of Agricultural Research (Nigeria)
IBU	International Bitter Unit
ICSM	Instant Corn-Soya-Milk
IDRC	International Development Research Centre (Canada)
ILCA	International Livestock Centre for Africa (Ethiopia)
INRA	Institut national de la recherche agronomique (France)
INTSORMIL	USAID Title XII International Sorghum/Millet Collaborative Research Support Program (USA)
IRAT	Institut de recherches agronomiques tropicales et des cultures vivrières (France)
ISRA	Institute senegalais de recherches agricoles
LCEC	low-cost extrusion cooking
LSD	least significant difference
NARS	national agricultural research system
NDF	neutral detergent fiber
NRI	Natural Resources Institute (UK)
OAU	Organization for African Unity
ODA	Overseas Development Administration (UK)
ODNRI	Overseas Development Natural Resources Institute (UK)
PFIAU	Post-Harvest Food Industry Advisory Unit (Zimbabwe)
PIU	period for industrial utilization
PRL	Prairie Regional Laboratory (Canada)
RH	relative humidity

RIIC	Rural Industries Innovation Centre (Botswana)
SAFGRAD	Semi-Arid Food Grain Research and Development (Nigeria)
SACCAR	Southern Africa Centre for Cooperation in Agricultural Research (Botswana)
SADCC	Southern African Development Coordination Conference (Botswana)
SAP	Structural Adjustment Programme
SDU	sorghum diastatic unit
SIDA	Swedish International Development Agency
TADD	Tangential Abrasive Dehulling Device
TNO	Institute for Cereals, Flour and Bread (Netherlands)
TPI	Tropical Products Institute (UK)
UMS	United Milling Systems (Denmark)
UNESCO	United Nations Educational, Scientific, and Cultural Organization
UNICEF	United Nations International Children's Emergency Fund
USAID	US Agency for International Development
USDA	US Department of Agriculture
VOICE	Voluntary Organization in Community Enterprise (Zimbabwe)